

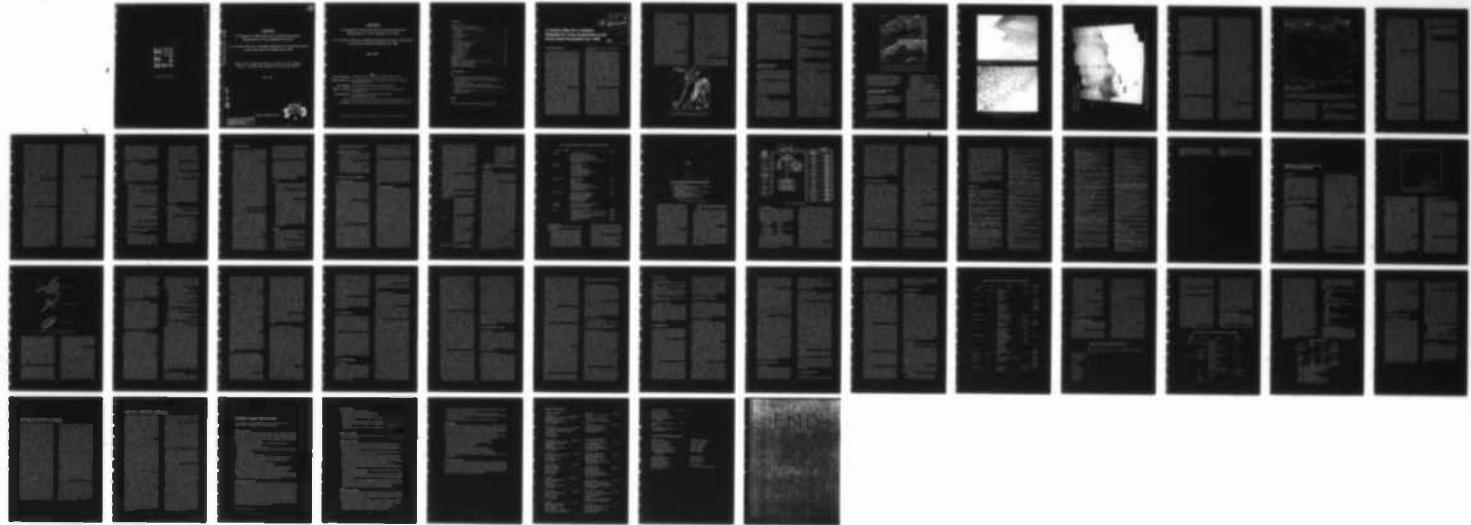
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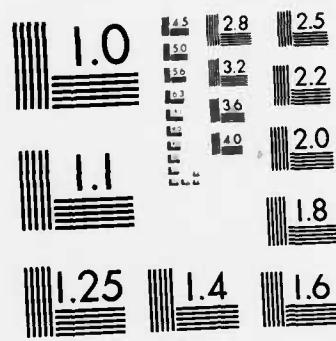
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MIZEX

A Program for Mesoscale Air-Ice-Ocean Interaction
Experiments in Arctic Marginal Ice Zones

II. A Science Plan for a Summer Marginal Ice Zone Experiment in the Fram Strait/Greenland Sea: 1984

Editors: Ola M. Johannessen, William D. Hibler, III, Peter Wadhams
William J. Campbell, Klaus Hasselmann, Ira Dyer, Max Dunbar

May 1983

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II. A Science Plan for a Summer Marginal Ice Zone Experiment in the Fram Strait/Greenland Sea: 1984

May 1983

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A Science Plan for a Summer Marginal Ice Zone Experiment in the Fram Strait/Greenland Sea: 1984

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EXECUTIVE SUMMARY

This document describes a plan for a mesoscale experiment to study the physical processes by which ice, water and atmosphere interact in the outermost parts of a polar icefield, the region known as the marginal ice zone (MIZ). During the last two decades a series of large projects culminating in the Arctic Ice Dynamics Joint Experiment (AIDJEX, Pritchard 1980) yielded considerable understanding of the growth, motion and decay of sea ice in the interior of the Arctic Ocean. With these experiments concluded, and coupled nonlinear sea ice dynamic-thermodynamic models in hand (Hibler 1979, Coon 1980), attention shifted to the problem of understanding the processes which occur near the open ocean boundaries of polar icefields, and which determine the advance and retreat of the sea ice edge. The exchanges which take place in this zone affect hemispheric climate and have a significant effect on naval operation and commercial fisheries.

The U.S. National Academy of Sciences has recommended studies of the marginal ice zone in their documents entitled *U.S. Contribution to the Polar Experiment, POLEX, Part 1—North and Part 2—South* (NAS 1974). A workshop in Monterey in 1979 (Andersen et al. 1980) summarized the extent of the problem and the paucity of our knowledge. In response to this and to a series of research recommendations by international bodies (WMO-ICSU 1975, 1978), including most recently the Joint Scientific Committee in its plan for the World Climate Research Program (WMO-ICSU, JSC 1981), efforts began towards the design of an integrated research program to tackle the problem

of understanding the nature of the unconfined sea ice margin.

As a result of a workshop in Voss, Norway, in 1980, and subsequent meetings, a program emerged which has two complementary aspects. The overall problem of understanding the annual and interannual variability of the polar ice margins, and of relating these to the large-scale behavior of the atmospheric and ocean circulations, is to be addressed by a long-term monitoring and modeling program described in an associated document (*Air-Sea-Ice Research Programs for the 1980s*, Untersteiner 1983). Complementary to this program will be a mesoscale experimental program to study physical processes occurring within the MIZ and to develop models of these processes. This is known as the Marginal Ice Zone Experiment (MIZEX), and a research strategy for it, the MIZEX-1 Report, was issued in June 1981 (Wadhams et al. 1981). The present document describes a science plan for carrying out the summer portion of this research.

Both the northern and southern polar regions have substantial marginal sea ice perimeters. However, the remoteness of Antarctic sea ice increases greatly the cost of multi-ship experiments with aircraft remote sensing support. As a consequence it was decided that an intensive marginal ice zone program should take place first in the Arctic area of greatest importance thermodynamically, i.e. the region north and west of Svalbard. Fram Strait handles most of the heat and water exchange between the Arctic Ocean and the rest of the world, and therefore is a crucial area for studying energy interactions across the ice margin. The shallow Bering Sea, which is a MIZ

of quite different character without large velocity shear, is being studied in a parallel program which was initiated in early 1983 (Martin et al. 1982). This program will share many personnel, instruments and experimental concepts with the Fram Strait/Greenland Sea MIZEX.

Physical processes in the MIZ are different in winter than in summer, and experiments in both seasons are needed. The first major experiment is to take place during a six-week period from mid-June to the end of July 1984, and is to be preceded by an initial study in 1983. The dates are chosen to cover the melt period and the transition to summer ice dynamics. The 1983 study is designed to test whether the scales for the experimental arrays, and the cooperative measurement procedures, are appropriate for yielding the maximum amount of information. The 1984 summer experiment is described in this document, with a brief summary of the 1983 experiment (Section 4.4). Winter experiments will follow in 1986-1987.

The experiment is designed as a drifting one in which an area some 200 km square enclosing the ice edge is selected for intensive investigation. The center of the area is a ship moored to the ice some 30-50 km inside the ice edge and serving as the base for an array of transponders to measure ice deformation as well as for experiments on ice

properties, the atmospheric boundary layer and the upper ocean. Other ships are dedicated to studies deeper inside the pack (requiring a heavy icebreaker), at the ice edge itself (where fronts, eddies and ice edge features will be mapped) and in the open water outside the ice edge. The work of these ships will be coordinated by a Field Coordinator aboard one of the vessels, and the concept of following the downstream development of the MIZ ice will be combined with a fixed geographical grid for CTD measurements of ocean structure. Regular remote sensing flights will map the entire "moving box" with synthetic aperture radar, microwave sensors and cameras, and will transmit imagery of the ice edge either directly to the ships by downlink or indirectly via the Tromso Satellite Station in northern Norway, which will be the communications base for the experiment. As well as being a tool to assist in the experimental scheme, the remote sensing program is designed to increase our knowledge of the active and passive microwave signatures of sea ice in summer. Included in this effort will be in situ as well as aircraft-based studies.

The scales of the arrays employed, and the set of measurements to be made, will be governed by the needs and results of MIZ modeling studies which will be coordinated through a MIZEX

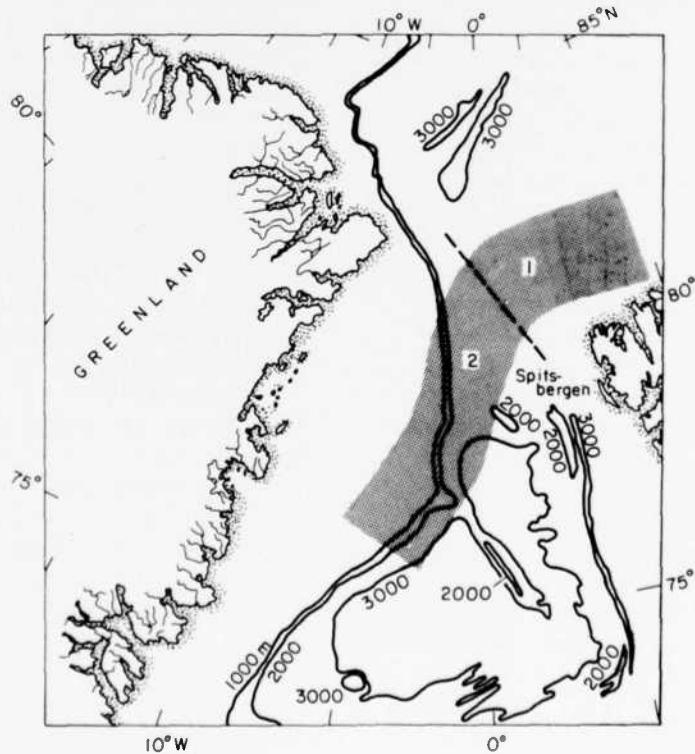


Figure 1. A possible area swept out by the experimental box in six weeks, assuming a mean advection rate of 10 cm s^{-1} .

Modeling Group. Figure 1 shows a possible area that will be traced out by the ships and arrays during the six-week period of the experiment, assuming initial deployment northwest of Svalbard. The initial region, area 1, is a zone of relatively low ice advection with normally a compact and well-defined ice edge. Once Fram Strait is encountered (area 2) the ice drift in the MIZ becomes much more rapid and the ice edge is likely to be more irregular and complex in form.

At every stage MIZEX is planned to be closely coordinated with other experiments in the region. As the ASI program develops, MIZEX will be able to define the major energy interactions which need to be parameterized for use within the larger-scale grid of the ASI program. A separate Fram Strait Monitoring Program has been proposed, sponsored by the Comité Arctique. MIZEX will cooperate closely with this program to achieve maximum scientific value and avoid duplication of facilities. Lastly, the ships of MIZEX will provide a unique platform for important biological and acoustical studies in the MIZ region. Summaries of these latter programs are given in Appendices B and C.

I. SIGNIFICANCE OF THE MARGINAL ICE ZONE

The marginal ice zone is a significant region in two senses, firstly as a location for man's activities and secondly as an important geophysical boundary zone involving energy exchanges which require parameterization in large-scale ocean-atmosphere models.

The MIZ is subject to fluctuations due to short-term forcing (e.g. cyclone passages, eddy generation) and to longer-term factors (seasonal and interannual). Successful modeling and prediction of variations in ice edge position and ice concentration would be of great value in furthering man's activities in the region. There are several areas of special interest.

Arctic navigation

Present and future developments in offshore Arctic oil exploration, in seaborne transport of Arctic resources (e.g. liquefied natural gas, iron ore), and in the supplying by sea of rapidly growing Arctic communities all require a much better predictive capability for ice conditions. We need the ability to predict the blockage or opening of ports and channels, the opening or closure of shore leads or large leads within the pack, changes

in the motion and concentration of the ice, and the development of any ice edge anomalies. Typical ice-strengthened cargo vessels, for instance, can proceed even in multi-year ice so long as the ice-field is open, but encounter difficulties in consolidated pack of any age. The richest fisheries in the North Atlantic lie close to the ice margin, and the development of Antarctic krill harvesting will produce an increase in ship activity close to the Antarctic ice edge; in both cases a predictive capability for the ice margin is highly desirable.

Biology

The biological regime in the MIZ is scarcely assessed at all, and a knowledge of the impact of ice margin processes on biological productivity would be of great value to the development of fisheries.

Naval operations

The upper ocean in the MIZ is a region of extreme acoustic variability as well as having a high ambient noise level due to ice floe collisions. These effects interfere with the propagation of underwater sound.

Climate

An indication of the variability of the MIZ in the Greenland Sea, both from month to month and from year to year, is given by Figure 2, which shows mean and extreme limits for winter and summer over a 10-year period.

As a geophysical boundary zone the MIZ is unique in the complexity of the vertical and horizontal air-sea-ice energy interactions which take place there. In response to these the ice edge moves hundreds of kilometers north and south on a seasonal cycle. If the physical processes which occur on the mesoscale in the MIZ can be parameterized and included in large-scale models such that the ice edge motion can be understood, the results will be valuable not only to man's immediate activities but also to the study of the hypothetical response of the ice-covered oceans to major global disturbances. We would then be able to answer the question: Where would the ice edge lie if significant changes in certain energy fluxes occurred (e.g. effect of a dust veil due to volcanic eruption or meteoric impact, effect of a major increase in CO₂ or other atmospheric pollutants)?

There have already been some empirical studies which demonstrate a strong correlation between ice margin variations and interannual atmospheric variability (Walsh and Johnson 1980, Kukla and Gavin 1981, Vinnikov et al. 1981), and CO₂ sensitivity simulations by Bryan et al. (1982) and Man-

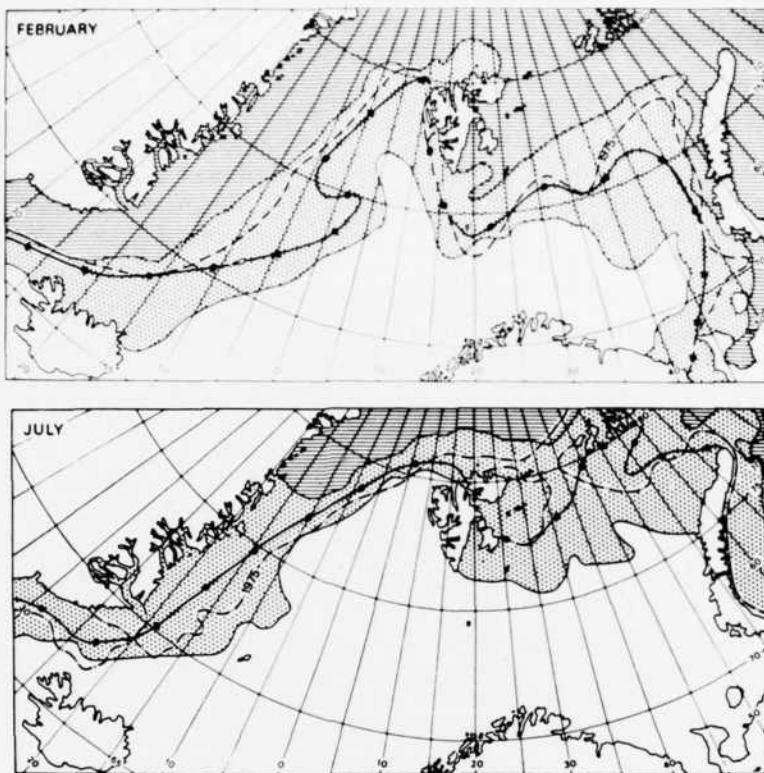


Figure 2. Mean and extreme sea ice limits at the end of February and July for the years 1966-1974 (Vinje 1977). The extreme range for sea ice cover is bounded by the dotted areas, while the thick black line is the median limit for the decade and the dashed line is the 1975 limit.

abe and Stouffer (1979) which indicate how strongly the insulating effect of sea ice affects the polar regions' climatic sensitivity. To proceed further in these important areas of research, it is essential to have a better grasp of the physical processes which govern the ice edge position.

2. MIZ PROCESSES, MODELS AND SCIENTIFIC QUESTIONS

In this section we describe physical processes which are of importance in the MIZ region, and we consider how they may be modeled and how this leads to a set of scientific questions which will be addressed in MIZEX.

2.1. Processes

2.1.1. Ice dynamics and thermodynamics

In the ice-covered oceans the growth, drift and decay of sea ice significantly modify the atmosphere-ocean interaction. The main effects are:

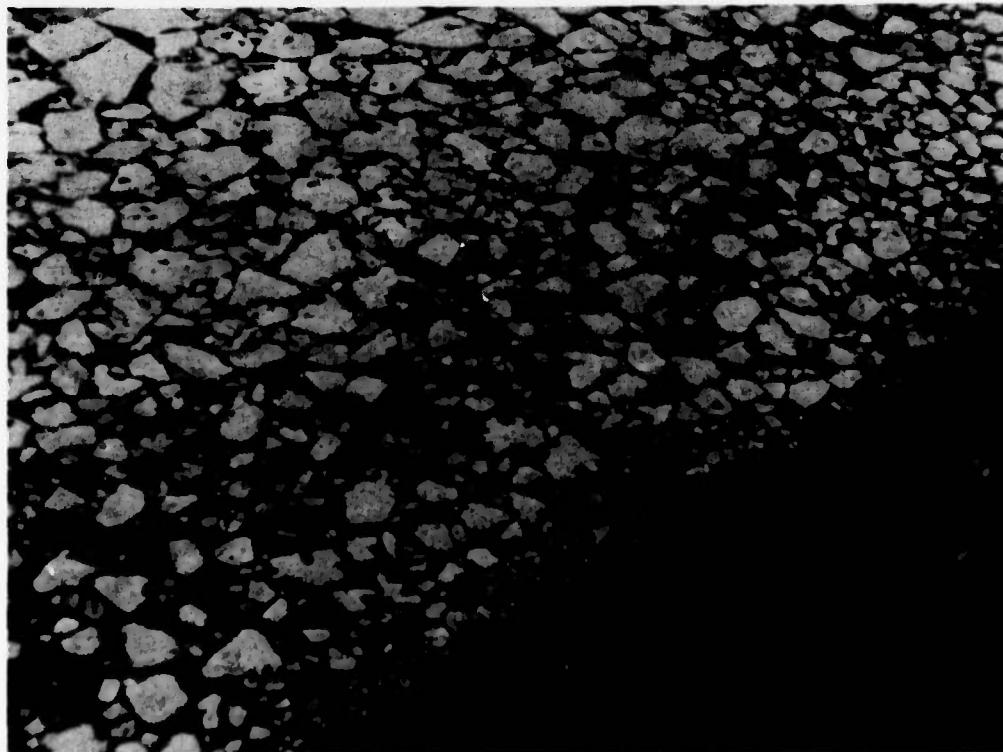
- i) modification of the thermal fluxes at the air/sea interface
- ii) modification of the buoyancy (salt) fluxes at the ocean surface
- iii) modification of the surface albedo
- iv) modification of the air-sea momentum exchange due to the ice interaction.

These modifications are particularly pronounced near the ice edge where the transition from ice to no ice occurs, and are further enhanced by the fact that the ice edge is in dynamic rather than static balance. Specifically, in the presence of a free ice edge, advective effects can transfer ice to the MIZ to be rapidly melted.

The nature of the ice in the MIZ is different from the interior pack, because of its greater freedom of movement and also because it is broken up by incident waves and swell into discrete floes which are small (about 30 m diam) close to the ice edge and which are larger at deeper penetrations where the wave field has been attenuated. These floes contain fragments of the original pressure ridges which traversed them when they were in the



a. Note small icebergs and the slicks of shallow internal waves just outside edge. (Photograph: P. Wadhams.)



b. The diameter of the larger floes is 50–80 m. (Photograph: P. Wadhams.)

Figure 3. The ice edge in Fram Strait.

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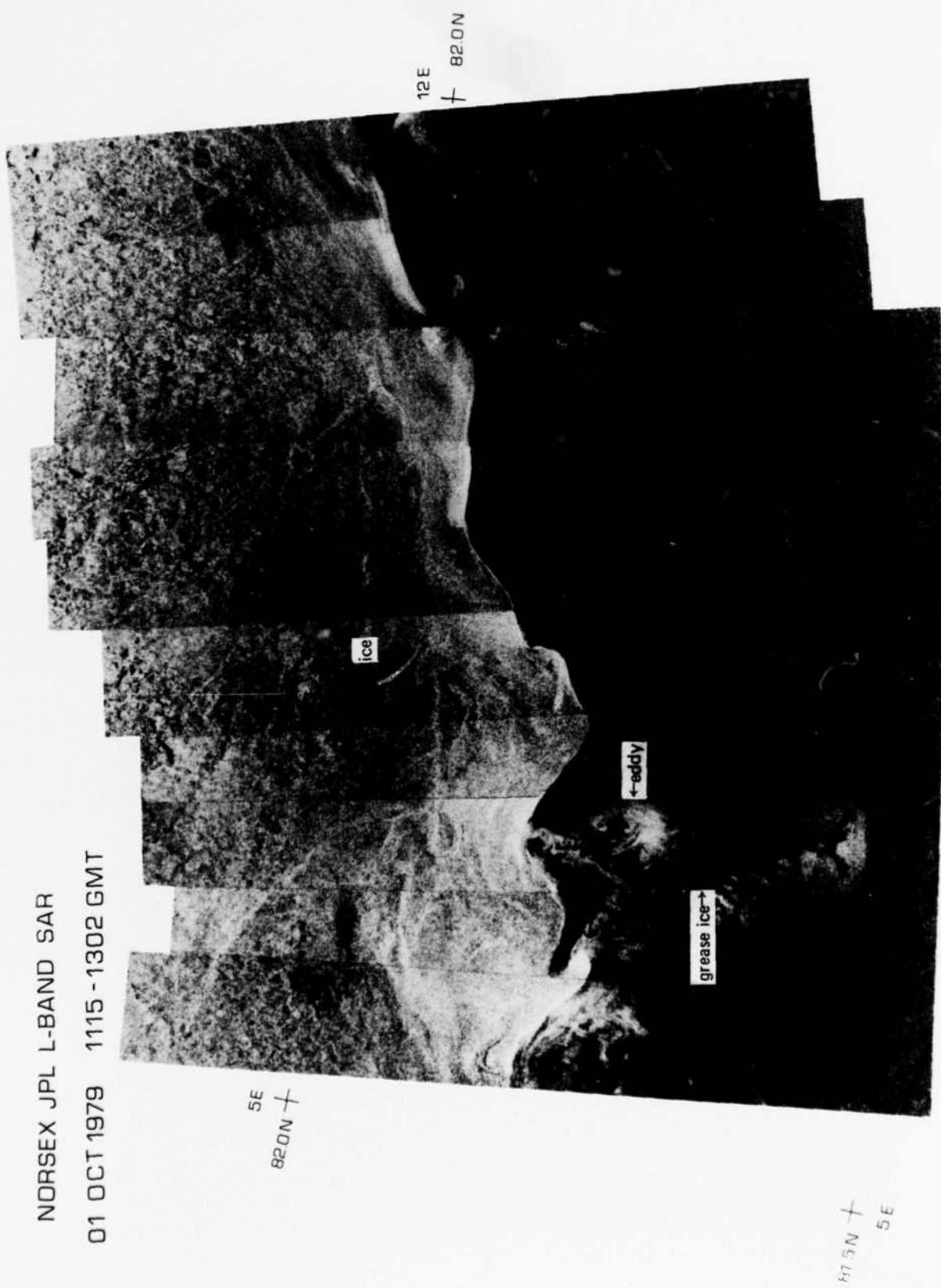


Figure 4. Synthetic Aperture Radar (1.215 GHz) image of the marginal ice zone on 1 October 1979 obtained during the NORSEX investigation. (After NORSEX Group 1983.)

interior of the pack, but it appears from submarine sonar profiles that considerable erosion of the ridge keels has occurred. The combination of less ridging with a greater number of floe edges produces air-ice and ice-water drag coefficients which are different from the interior pack and which seem, from the slender evidence available, to be somewhat higher (Johannessen 1970, Smith et al. 1970). The characteristic floe size distribution also affects the ice dynamics by determining the rate of the floe collisions by which kinetic energy is redistributed within the icefield, and affects the thermodynamics by enhancing the melt rate in summer (through lateral melting around floe edges) and the growth rate in winter (through the incessant opening and closing of new open water areas). Figures 3a and b show typical scenes at a compact ice edge composed of small floes broken up by wave action.

2.1.2. Oceanography

Oceanographic conditions in the MIZ are dominated by permanent and transient frontal systems, by eddies, and by upwelling events along the ice edge. Vertical fine structure (10 m) and mesoscale (100 m) structures formed by interleaving of Polar and Atlantic Water intrusions are also frequently observed in the Greenland Sea MIZ. These phenomena interact with the ice pack and the atmosphere. For example, salinity fronts off the ice edge develop strongly during summer due to meltwater input; eddies along the ice edge shed ice off into warmer water, thereby providing an ice export mechanism; surface boundaries of ocean fronts will limit ice extension particularly during winter because the ice will melt when forced across the boundary into warmer water by wind. Wind-driven upwelling along the ice edge is dependent on the ice roughness, the stability of the atmospheric surface boundary layer, and the ice interaction. Furthermore, there is a strong coupling between the ice pack and the oceanic mixed layer below it.

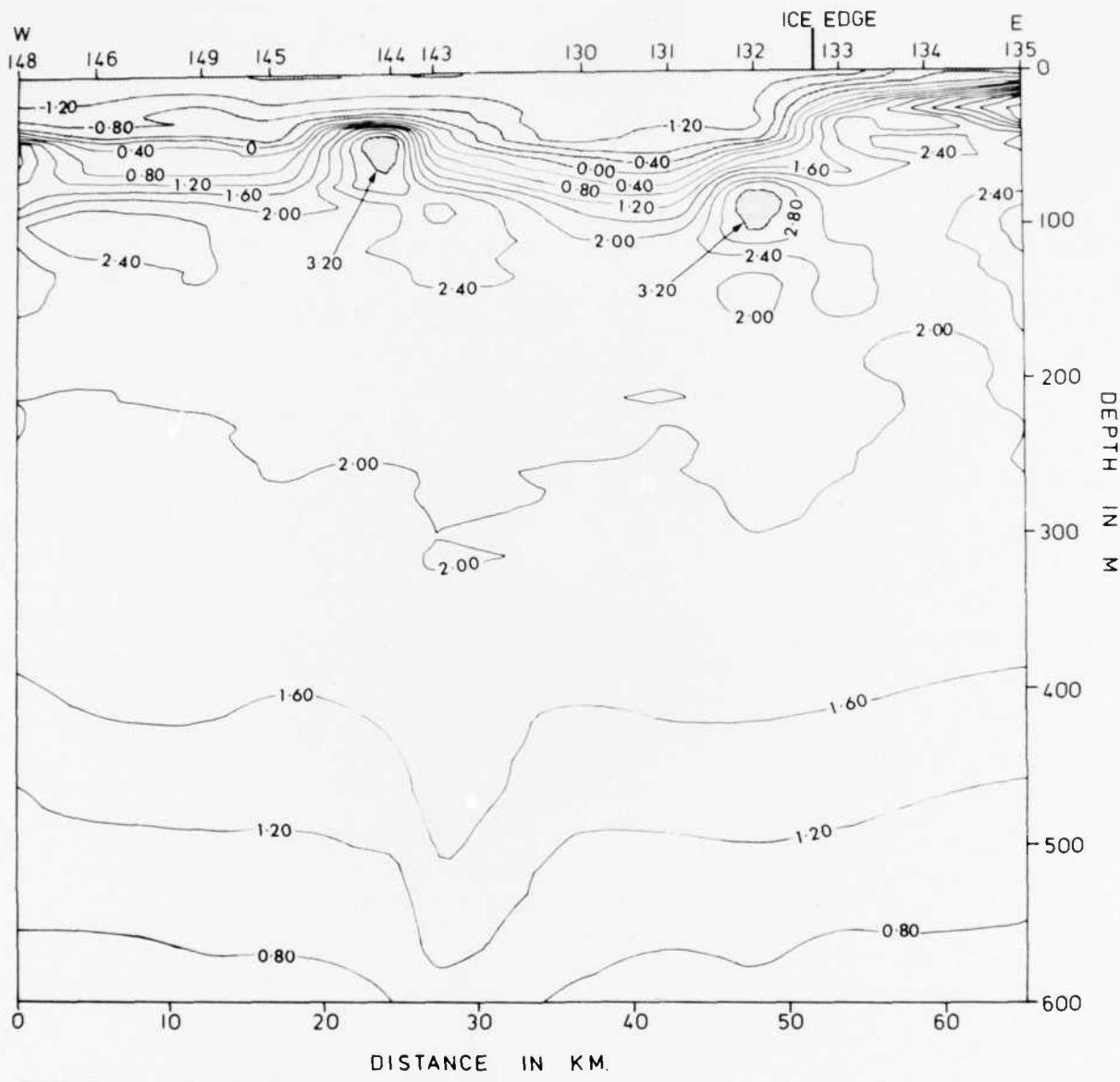
Fronts may be strong and permanent, such as the East Greenland Polar Front which separates the cold, low-salinity, southward-flowing East Greenland Current from the more saline water in the Greenland Sea; or more transient, such as ice edge meltwater fronts observed north of Svalbard. The wavelength of meanders observed on the meltwater front is in the order of 20–40 km (Johannessen et al. 1983), while the meander scale of the East Greenland Polar Front is longer (60–100 km). Several investigators, e.g. Perdue (1982), have established that the location of this front is

correlated with the continental slope in the Greenland Sea, thereby implying bathymetric steering.

Along the fronts and the ice edge, *eddies* have been observed which develop from frontal meanders. In the MIZ region north of Svalbard the horizontal scale is approximately the Rossby internal radius of deformation of 10 km (Johannessen et al. 1983, NORSEX Group 1983). Figure 4, an airborne SAR image obtained in this area during the Norwegian Remote Sensing Experiments (NORSEX Group 1983), shows eddies of this type being shed from the ice edge. The image, obtained on a cloudy day, demonstrates the capability of aircraft radars in collecting sequential mesoscale synoptic information in the MIZ. Further downstream in Fram Strait and the Greenland Sea, larger eddies of diameter 50 km or more are observed (Vinje 1977, Wadhams and Squire 1983) which appear to be generated through baroclinic instability of the polar front. Figure 5 shows a temperature section across such an eddy surveyed in Fram Strait during the Swedish YMER-80 cruise (Wadhams and Squire 1983); the effects of the warm core extended down to beyond 600 m. Our present knowledge of the space and time scales of these high-latitude eddies, and their generation, energetics and role in lateral heat and mass exchange in the MIZ, is very sparse.

Transient wind-driven upwelling along the ice edge has only been observed twice, in both cases north of Svalbard: in winter by Buckley et al. (1979) and in the fall by Johannessen et al. (1983). In the winter, water was upwelled from 150 m depth to the surface in a 10-km-wide zone along the ice edge, thereby generating two fronts, one coinciding with the edge and the other parallel to the edge and 10 km off. During the fall upwelling event, where the vertical stratification across the pycnocline (located at 20 m) was very strong, only a slight rise of the pycnocline, on the order of a few meters, took place during a 2½-day 10-m·s⁻¹ wind event. The upwelling is believed to be caused by changes in the wind stress across the ice edge due to the variation of the air drag coefficient between open water, broken ice floes and smoother ice, and to stability variations in the atmospheric surface boundary layer.

The planetary boundary layer and mixed layer under pack ice have been the subject of several studies, such as those of Hunkins (1966), McPhee and Smith (1976), Maykut (1977), Morison (1980) and Morison and Smith (1981). All of these have taken place in the interior pack, and it is expected that the boundary layer and mixed layer in the MIZ may behave quite differently. For instance,



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Figure 5. A temperature section across an eddy observed at the ice edge in Fram Strait, 79°15' N, 00°38' E, during the YMER-80 cruise, August 1980. The eddy is at station 144 and an ice edge front can also be seen (after Wadhams and Squire 1983). Shading indicates entrained Atlantic water warmer than 3.2°C.

the few measurements of air and water drag coefficients for MIZ ice suggest that they are greater than over the interior pack or open water (Johannessen 1970, Smith et al. 1970), while recent theoretical work by McPhee (1981) suggests that in summer the water drag coefficient is very low because of the effect of meltwater on the boundary layer. In the mixed layer it is possible that one-dimensional models of behavior are no longer ap-

propriate because of the large horizontal density gradients which may introduce vertical velocity shears, eddies or disruptions in the internal wave field.

2.1.3. Meteorology

The principal atmospheric processes that are important in the MIZ are those which control the ice edge through exchanges of atmosphere and

ocean or ice surface. The influence of the ice edge on the atmosphere is also of primary interest.

Wind stress is the atmospheric momentum flux at the surface. It contributes to ice drift, wave and current generation, and mixing in the upper ocean. The magnitude and direction of the stress are determined mainly by the gradient of sea level pressure and the stratification and shear in the atmospheric surface layer and planetary boundary layer (PBL). These effects are dependent on boundary layer exchange processes and mesoscale circulation features, thus creating a feedback between the pressure field and stress field. Wind stress is coupled to changing surface roughness in both the ice and the ocean. Critical MIZEX problems involve determining the wind stress under a variety of synoptic conditions, stratifications and surface characteristics.

The *sensible heat flux* to and from the atmosphere strongly influences ice growth, the temperature of the ocean surface, and convection in the upper ocean. Its magnitude and direction are a function of the temperature difference between the atmosphere and the surface, and, as in the case of stress, the details of the turbulent transfer are dependent upon stratification and shear in the surface layer and planetary boundary layer. In some cases, however, as when deep convection is generated during air mass modification, there may be strong vertical coupling between the surface and the mid-troposphere. Feedback may be involved if this convection further influences synoptic development. Relevant MIZEX problems involve relating the sensible heat flux to the ambient synoptic conditions and boundary layer characteristics.

The physics of water vapor transfer (evaporation and condensation) are analogous to those of sensible heat, and all the preceding remarks apply. Precipitation, usually rain or snow, enters MIZ problems in several ways. Precipitation over the ocean decreases the salinity of the mixed layer and affects thermohaline convection, and over ice may cause melting or a change in surface wetness. Snow over ice surfaces usually causes an albedo change, and strongly influences the heat transfer by conduction; it may also slightly alter the surface roughness.

The solar and infrared *radiative fluxes* are large terms in the energy balance of both the ocean and the ice. Both quantities are critically dependent on cloudiness, and to a somewhat lesser degree on atmospheric constituents, especially water vapor, carbon dioxide and aerosols. Albedo variations, especially over heterogeneous snow-ice-water surfaces, influence the short-wave fluxes, while varia-

tions of infrared emissivity affect the long-wave balance. The MIZEX radiative problem is chiefly one of monitoring the fluxes at the surface together with the ambient cloud and moisture conditions.

There are numerous topographic considerations involving the Greenland land mass. These involve all scales, ranging from katabatic effects in coastal regions to large-scale, orographically induced cyclogenesis.

2.2. Models

While models describing the sea ice in the Marginal Sea Ice Zone exist, a coupled mesoscale ice-ocean simulation of the MIZ has not yet been carried out. Some ice model simulations have been done for the Greenland Sea using Hibler's (1979) dynamic thermodynamic sea ice model to predict seasonal and interannual variations in the ice edge position (Hibler and Walsh 1982), and to predict week-to-week variations in ice drift and compactness (Tucker and Hibler 1982). The large-scale simulations (Hibler and Walsh 1982) yielded a seasonal cycle with excessive amounts of ice in the North Atlantic during winter and with somewhat excessive amounts of open water in the central Arctic during summer. The poor fit to the Atlantic ice margin in winter is likely partially due to the neglect of lateral oceanic heat transport, since the ocean portion of the model consisted of only a fixed depth, motionless mixed layer together with an upward oceanic heat flux. However, a similar model has successfully simulated the seasonal cycle of Weddell Sea pack ice (Hibler and Ackley 1983) indicating that there may be considerable asymmetry between the oceanographic characteristics in the different hemispheres. In general these results emphasize the need for carrying out more fully coupled ice-ocean simulations in the marginal ice zone regions.

To model ice drift, growth and decay it is important to understand the nature of the ice rheology. In the MIZ the ice cover is more fragmented than ice in the central pack, with substantial variations in compactness. These MIZ characteristics have an unknown effect on the ice dynamics. Of particular interest is the role of internal ice stress as compared to wind and water stresses on the ice drift. On the large scale the internal ice stress has a rectifying effect on motion in the marginal ice zone. In particular, under on-ice winds, this stress tends to reduce further convergence after the ice has been sufficiently compacted. Off-ice winds, on the other hand, can cause motion with little ice resistance. Such features are characteristic of the

plastic rheologies used in large-scale models (e.g. Hibler 1979, Coon 1980). However, superimposed on such a rectifying effect, random bumping or rotation of floes may produce an effective pressure term. Røed and O'Brien (1981) speculate that such an unconfined pressure may be a mechanism causing a jet-like motion at the ice edge. In addition, mesoscale simulations by Hibler et al. (1983) show the presence of wave effects during ice build-up. To methodically examine the role and effect of these rheology features on ice edge growth, drift and decay further numerical simulations are needed. Such studies can be carried out using the viscous plastic numerical model developed by Hibler (1979). This numerical model provides for the simulation of a highly nonlinear ice interaction employing an arbitrary shear to compressive strength ratio, and an unconstrained pressure term of adjustable magnitude.

The specific problem of the ocean response to wind forcing in the MIZ has been approached through analytical work invoking a stationary and inactive ice cover, which readily allows ice edge upwelling (Gammelsrød et al. 1975, Clarke 1978). However, direct observation of the MIZ reveals a highly mobile rather than inactive ice cover, and emphasizes the need for a coupled ice-ocean model. Mesoscale numerical models, coupling sea ice and ocean (Røed and O'Brien 1983) and including thermodynamic processes, are under development. They will be used in studying the influence of a moving ice cover on the oceanic circulation in the MIZ on short time scales of a few days to a few weeks.

There is also a need for more complete models of the atmospheric winds. One approach in this regard is to study the mesoscale wind and surface flux fields employing planetary boundary layer (PBL) models. Models for obtaining the surface flow, stress and heat fluxes with respect to large-scale parameters of pressure and temperature fields were developed during AIDJEX (Brown 1974, 1981). The model developed by Brown was adapted to the ocean in connection with GOASEX and JASIN for remote sensing surface truth studies (Brown and Liu 1981). In these experiments, model fields were shown to agree with point measurements to $\pm 2 \text{ m s}^{-1}$ and $\pm 20^\circ$. The geostrophic flow (derived from the surface pressure field) is corrected for curvature effects and thermal wind. It is used as the boundary condition on a two-layer similarity solution for the PBL flow. Corrections are included for stratification effects in both layers, secondary flow in the outer layer, variable surface roughness and humidity effects.

The mesoscale eddies which occur along the ice edge have already been subjected to laboratory modeling (Griffiths and Linden 1981a, b), but further numerical modeling is required in order to understand this phenomenon. We plan first to examine the dynamics of isolated mesoscale eddies found in the MIZ region through the use of an existing two-layer dynamical numerical model (Smith and O'Brien 1982). The roles of topography, vertical eddy structure, variable friction and lateral boundaries can all be addressed with the model, and there is the possibility of incorporating thermodynamics. More complete studies will likely involve the coupling of a nonlinear dynamic-thermodynamic sea ice model to an eddy resolving baroclinic ocean model. Preliminary numerical experiments will aid in the design of the eddy sampling program in MIZEX.

On a smaller scale, ocean waves are important in breaking up the ice in the MIZ, and long swell may be effective up to 50–60 km inside the ice edge. Present models of the interaction of waves with an array of discrete ice floes (Wadhams 1983) are based on scattering mechanisms and are successful in predicting the wave decay rate so long as the pack is not consolidated. They cannot, as yet, predict wave refraction within the pack or the form of the energy spectrum reflected back out into the open water. The flexural response of floes to waves can also be modeled successfully (Goodman et al. 1980) and used to predict the maximum floe size that can occur at different penetrations into the ice pack under a specified incident wave spectrum. The actual nature of the floe size distribution within this maximum size limit is not predictable as yet, but has been measured empirically.

To summarize, several of the mesoscale MIZ processes are poorly described theoretically. Regional models exist which will couple a uniform depth mixed layer both to the ice and to the deep ocean but have not been numerically investigated. In addition there is a need for development of a model for the Greenland/Norwegian Seas, employing a more complete treatment of the mixed layer and including the three-dimensional circulation of the ocean. Such studies, which are proposed in the ASI program, will help in the understanding of the physical processes which control the East Greenland and West Spitzbergen Currents and the ice edge position.

To aid in the further development of models describing the marginal sea ice zone, a subgroup of researchers interested in modeling has been organized. At the moment there are a variety of theories explaining various aspects of the MIZ. Because of

this variety it is important to not prejudice the design of the experiment until different theories have withstood the test of open debate. In this regard it is felt that premature focusing of the experiment can be as destructive as inadequate focusing of the experiment. Data from the 1983 and 1984 studies, in conjunction with ongoing modeling efforts, should allow this focus to emerge.

2.3. Scientific questions

The foregoing discussions of processes and models suggest that the determination of the major scientific questions will arise from the dialogue between the modelers and experimentalists occurring during the 1983-84 MIZEX studies. Consequently a more complete focus must await their efforts. However, at this point in time, a number of scientific questions of major importance have been identified. These include the following.

2.3.1. Sea ice

- What are the roles of the internal ice stress, floe-floe interaction, wind and water stresses, inertial-tidal forces, and wave forces in MIZ ice dynamics?
- What is the relative importance of the ocean vs the atmosphere in the decay of the ice cover and how is this affected by changes in ice concentration and floe size distribution?
- Are lateral variations in vertical oceanic heat fluxes more important than horizontal oceanic heat transport in determining the ice retreat?
- How does ice advection caused by general circulation such as the East Greenland Current, by eddies, ice bands and streamers, influence the retreat of the ice edge?
- How do the physical properties (and hence thermodynamic and electromagnetic properties) of the MIZ ice differ from those of the central pack?
- How does the ice thickness distribution and ice roughness vary with distance from the ice edge?
- What is the role of waves in the distributions of floe size and ice roughness?

2.3.2. Oceanography

- What is the three-dimensional structure of the fronts (East Greenland polar front and meltwater fronts) in the Fram Strait and Greenland Sea marginal ice zones? What is their temporal and spatial variability over a

period of days? What is the relationship between the fronts, the ice edge and the bathymetry? How do instabilities, eddies and fine-structure occur in relation to fronts?

- What are the characteristics of the eddy field in the MIZ with respect to space and time scales, energies, generation mechanisms, propagation and role in lateral heat and mass exchange?
- How prevalent is upwelling along the ice edge? How does it relate to the wind-stress variation across the edge and is it important to the dynamics and thermodynamics of the ice edge region?
- How do the momentum, buoyancy, and heat fluxes in the oceanic mixed layer vary with varying ice conditions (melting rate, concentration, floe size, etc.)?
- How does meltwater input affect stratification and the upper layer circulation in the MIZ? Does the meltwater, for example, generate a jet-like current along the ice edge by analogy with coastal currents, with fresh water inputs from fjords and estuaries?
- How does the internal wave field differ under pack ice and in the open ocean?
- What is the role of vertical fine-structure in the transfer of properties across the front?
- What are the sources of near-surface water?
- How long ago did fresh water runoff enter the ocean?

2.3.3. Meteorology

- How does the surface wind stress field vary with ice conditions?
- What are the energy fluxes (heat and radiation) and their relation to conditions in the MIZ?
- How is the air modified by the change in boundary conditions at the MIZ?
- How do the bulk aerodynamic coefficients change with the ice conditions and atmospheric surface layer stability in the MIZ?
- What is the relationship between synoptic scale pressure patterns and surface wind flow in the region surrounding the MIZ?
- What is the relative proportion of continental and marine aerosols in the MIZ?
- What are the effects of the aerosol populations on optical energy propagation?
- What marine aerosol enhancement occurs due to biological species in the MIZ?

3. REMOTE SENSING

Remote sensing is both a tool and a discipline. As a tool it is an essential part of fulfilling the goal of MIZEX. It is the only way to obtain mesoscale synoptic coverage at frequent time intervals and at sufficiently high resolution to provide useful information on ice and ocean parameters such as the ice edge location and structure (Fig. 4).

It is clear that remote sensing as a discipline will be advanced during MIZEX. The focus of the remote sensing experiments is on use of microwave sensors since they permit observation of ocean and ice surfaces through clouds. In spite of much research conducted in respect to microwave detection of sea ice during the last decade, i.e. BESEX, Gloersen et al. (1975), AIDJEX, Campbell et al. (1979), and NORSEX Group (1983), very little work has been done during the summer season. Many ambiguity problems are known to exist at this time of year due to snow melt and continual refreezing of ice surfaces. For example, passive microwave techniques yield good estimates of ice concentration when the ice is frozen (Svendsen et al. 1983), but we are not sure how well this technique will work for wet ice. Another example is the SAR observations. This technique presently provides information about the ice edge and structure, as well as surface and internal waves in the ocean. However, we have not yet shown how useful the SAR is for estimating ice concentration and ice floe distribution during summer, and for locating fronts and eddies in the open ocean off the ice edge in cold water.

The objectives of utilizing remote sensors in MIZEX are threefold.

1. To provide remote sensing products such as SAR, SLAK, passive imagery and aerial photography (dependent on weather) to MIZEX principal investigators. These data will be supplied to investigators in near real-time for the purpose of planning in situ data collection during MIZEX. Other remote sensing mosaics will be provided shortly after the actual field experiment to facilitate a better understanding of the synoptic scale processes occurring during MIZEX. Thus, one role remote sensing will play in MIZEX is to provide boundary conditions and baseline data of the environment of the MIZ experimental zone.

2. To carry out extensive microwave active-passive observations from aircraft, satellites (if available), and surface-based remote sensing systems, and to evaluate the ability of remote sensors to provide detailed geophysical information with respect to the ice and ocean areas found within the MIZ. In order to perform this evaluation nearly

coincidentally with the remote sensing data collections, in situ physical measurements of the ice and ocean will be made. Thus, the second objective of using remote sensors in MIZEX is to evaluate existing algorithms and develop new algorithms, where appropriate, that take remote sensing data as inputs and provide useful geophysical information.

3. To develop models that adequately explain and predict remotely sensed electromagnetic radiation signatures of both ice and ocean features. It has long been recognized that to optimize remote sensing algorithms the theory of radiation transfer must be well understood. This better understanding of the theory of how remote sensors measure ocean and ice parameters will be a prime scientific question addressed during MIZEX.

The specific scientific questions are:

3.1. Ice

- How do we relate signatures in radar images of the MIZ to the actual microwave cross section of various ice types during the melting season?
- How do the active and passive microwave signatures of different ice types vary during the melt season? What minimum resolution (both spatial and frequency) is necessary to detect various ice types?
- Which remote sensing system, active, passive, or a combination of systems, is most effective in providing data on ice concentration, ice types, ice floe distributions, and ice and ocean kinematics in the MIZ during summer? Additionally, a set of algorithms for the above required ice information needs to be designed, constructed, and evaluated.
- Which remote sensing system, or combination of systems, is most effective in providing data on measurement of gravity waves as they propagate into the ice? Can the SAR successfully image these waves as they attenuate in the ice?

3.2. Ocean

- How do we relate microwave signatures of the sea surface to phenomena such as fronts and eddies in cold-water regions?
- Can the SAR successfully image gravity waves as they refract due to interaction with the ice edge?
- Which remote sensing system, active, passive or a combination of systems, can provide the most useful information on ocean circulation in the MIZ?
- How do conditions near the ice edge affect

Bragg scatter and hence influence radar images and wind vector scatterometry?

3.3. Atmospheric remote sensing

- How accurate are infrared and passive microwave temperature and moisture retrievals in the MIZ in view of complex PBL characteristics and extensive Arctic stratus cloud conditions?
- Can satellite visual, infrared, and microwave radiances be used to determine weather and cloud characteristics in the MIZ?
- Can remotely sensed atmospheric profiles be used to analyze the troposphere in the MIZ and to initialize regional numerical models?

4. STRATEGY OF THE EXPERIMENT

4.1. Location and timing

The MIZ of the Fram Strait and Greenland Sea has been chosen for the main MIZEX experiments because it is the region where most of the heat and mass exchange takes place between the Arctic Ocean and the rest of the world, and is therefore of crucial importance thermodynamically. Furthermore, the length of the ice edge, which is expected to be traced out by the drifting experiment, combines many of the most interesting features of all marginal ice zones.

The initial deployment of the ships and arrays will be northwest of Svalbard (Fig. 1, area 1) where the ocean structure is characterized by a meltwater front off the ice edge. The edge is normally compact and well defined, and the downstream advection of ice is relatively slow and dominated by the prevailing winds. Small eddies and upwelling have both been observed in this region, which is also the place where a warm subsurface current, which was the West Spitzbergen Current when it was at the surface, proceeds northward into the Arctic Basin to act as that basin's major heat source.

As the ships and arrays drift down into the Fram Strait (region II) they enter a zone of rapid advection where the ice drift is dominated by the strong southward-flowing East Greenland Current. This is a permanent current whose speed and course are related to bottom topography, and which has a very sharp polar front on its seaward edge associated with a large velocity shear. This favors the development of meanders and eddies, which are of larger scale than further north. There is intense atmospheric frontogenesis. The ice edge tends to be irregular in form and to show by its

shape and concentration the effect of the many processes that have acted on it. A further reason for selecting the Greenland Sea lies in the assistance that MIZEX can give to the ASI program in its investigation of such problems as the source of North Atlantic bottom water, which may come from the sinking of Greenland Sea water in winter.

The timing of the experiment (mid-June to end of July 1984) is chosen to yield as much information as possible about the transition to summer conditions in the MIZ. Many cycles of melting and refreezing of the upper ice surface should occur in the early part of this period, before the final formation of summer melt ponds, and this will provide a good range of conditions for microscale measurements of ice properties and thermodynamics, and for microwave studies of the upper ice surface. The main ice, ocean and atmospheric programs will benefit from the continuous daylight.

4.2. Experimental design

As described in the *Executive Summary*, the experiment is a drifting one making use of a passive ship within the pack for many of the studies. In all, five ships are required, with five helicopters and a number of remote sensing aircraft. The drifting ship will position itself far enough into the pack (some 30–50 km) to be in a zone of large floes at high concentration, and with an average southward drift of 10 km day^{-1} it will cover a distance of some 400–600 km during the experiment.

Intense synoptic oceanographic, meteorological, and ice mapping will be carried out in fixed geographical grids (dependent on the ice edge location in 1984) in the northerly low advection region, area 1 (Fig. 1) and further downstream in the higher advective region, area 2 (Fig. 1) in the East Greenland Current. The two regions of intense synoptic mapping will each cover approximately a 100- to 200-km length of the ice edge, starting 40–50 km outside the ice margin and extending 40–50 km into the pack. The drifting ship, the ice-strengthened ship and the open-water ship with the ice deformation, meteorological pressure and the ocean mixed layer arrays will drift throughout the regions and provide observations of ice drift, and oceanographic and meteorological parameters. The ice-strengthened and the open-water ship will follow parallel tracks. The oceanographic grid lines are directed perpendicular to the ice edge, and tentatively spread 5–10 km apart with oceanographic stations spaced 2–4 km apart in order to resolve the smallest eddies with a diam-

eter of 10-15 km. Grid point distortion due to ocean advection and slow-moving ships will be corrected by applying a Space-Time Objective Analysis scheme (Carter and Robinson 1981). We are proposing that AXBT mapping of the high advection region in the East Greenland Current, area 2, start at the same time as the mapping in the low advective region in the north, so that the synoptic temperature field for the Fram Strait-Greenland Sea will be simultaneously observed at regular intervals during the 6-week experiment.

In the open ocean off the ice edge, several subsurface current meter moorings will be deployed as well as Argos and RDF drifters, and surface current measurements will be accomplished by the CODAR system.

We hope to obtain sufficient flight time for the remote sensing and meteorological aircraft to overfly the mesoscale experimental area every 2 to 3 days. An aircraft coordination center located at Tromso Satellite Station in northern Norway will coordinate all aircraft flights and quickly transmit selected remotely sensed information back to the scientists on board the ships to aid in the execution of the experiment.

To achieve our scientific aims it is necessary to use the following range of reliable state-of-the-art measuring systems:

Atmosphere	Standard ship meteorological instruments. Eddy flux, profile and dissipation sensors, aerosol counters, radiometers, acoustic sounder, radiosondes and pressure sensors on ships and buoys. Gust probes, dropsondes, scatterometer and other remote sensors from aircraft.
Ocean	CTD, bathymetry, free-falling velocity probes, current profiling systems, Argos-tracked drifters and CODAR radar for surface current and expendable probes for temperature and salinity profiles.
Ice	Deformation array, floe collision sensors, directional wave buoys, upward-looking ice profirometer, sonic ablation detector and parachute-dropped buoys tracked by Argos.
Remote sensing	X-, C-, L-band airborne synthetic aperture radars. Ka-

band imaging radars, multifrequency microwave radiometers and scatterometers. Portable in situ ice dielectric system. In situ multifrequency scatterometers and multifrequency passive microwave array. Raft-mounted Lunenberg target calibration lenses.

The role of these and other instruments in the overall plan of measurements is described in detail in Appendix A.

4.3. Platforms

The work program, described in detail in Appendix A, requires the participation of five ships, of which three must have the capability of operating in ice. The division of work among the ships is summarized in Table 1.

The icebreaker will be the R/V *Polarstern* of the Alfred Wegener Institute for Polar Research, Bremerhaven, Federal Republic of Germany. She can carry two helicopters and has space for approximately 45 scientists. The vessels to fulfill the roles of "drifting ship in ice" and "ice-strengthened ship" are anticipated to be the Norwegian ships *Polar Queen* (two helicopters, 30 scientists) and *H.U. Sverdrup* (space for 10 scientists), both of which will be chartered by the Office of Naval Research, U.S.A. One of the open-water ships will be R/V *Hakon Mosby* of the University of Bergen, Norway, with space for 10 scientists. A second open-water ship will be NAVOCEANO's *AGOR Lynch* (carrying about 15 scientists) which has been scheduled by the U.S. Naval Research Laboratory for three weeks in June 1984. Other ships that will participate in the experiment are the R/V *Valdivia* of the Institute for Marine Research, Hamburg, Federal Republic of Germany, with space for 15 scientists and the ice-strengthened vessel R/V *Lance* of the Norwegian Polar Institute, Oslo, Norway, with two helicopters and space for 20 scientists. The above set of ships will be able to accommodate the scientists and technicians required for the shipborne program.

The potential remote sensing aircraft are the CV580 of Canadian Remote Sensing Center equipped with ERIM SAR; the NRL P3, the Baron meteorological aircraft of Airborne Research Associates, the NOAA P3, and the NASA CV-990, all from the U.S.; the C130 of the Royal Danish Air Force carrying instrumentation from the Technical University of Denmark, a remote sensing aircraft from France, and a Norwegian Air Force P3.

Table 1. Tentative distribution of work commitments among platforms.

Platform	Heli-copters	Work	Days
Icebreaker	2	Synoptic CTD mapping in ice Deploy and retrieve met-ocean array in ice Deploy and retrieve four Cyclesondes Help ice-strengthened ship in heavy ice conditions Microwave properties of sea ice and CODAR Meteorological observations, radiosondes, acoustic sounder Biological measurements	22 5 3 6 6 6
Drifting ship in ice	2	Ice deformation and dynamics Ice structure studies Ice thermodynamics Cyclesonde deployment and retrieval Microwave properties of sea ice Hourly meteorological observations, radiosondes Acoustic sounder, flux profilers Atmospheric boundary layer studies Swallow float tracking	42 4
Ice-strengthened ship	1	Synoptic CTD mapping Eddy CTD mapping Upwelling Bands and streamers Detailed examination of ice front Deploy and retrieve directional wave buoy Hourly meteorological observations, radiosondes Atmospheric flux profilers CODAR, swallow float tracking	5 5 5 5-10 2 4
Open-water ships		Synoptic CTD mapping in open ocean Eddy CTD mapping-fronts and upwelling Deploy and retrieve met-ocean arrays Hourly meteorological observations Radiosondes, acoustic sounder Atmospheric boundary fluxes Aerosol size distribution	(each) 23 14 5
Submarine (if available)		Sonar profiling—20 transects with longitudinal ties Sound velocity profiling across fronts XBTs, CTD profiling across fronts	10
Aircraft		SAR mapping—long-range aircraft Correlative passive-active microwave data under different environmental conditions Combined meteorological-remote sensing aircraft for wind stress Boundary layer studies, surface temperature, albedo, roughness, ice distribution, photography. Marine winds from scatterometer AXBT flights	20 flights 15 flights 20 flights 20 flights 20 flights 10 flights

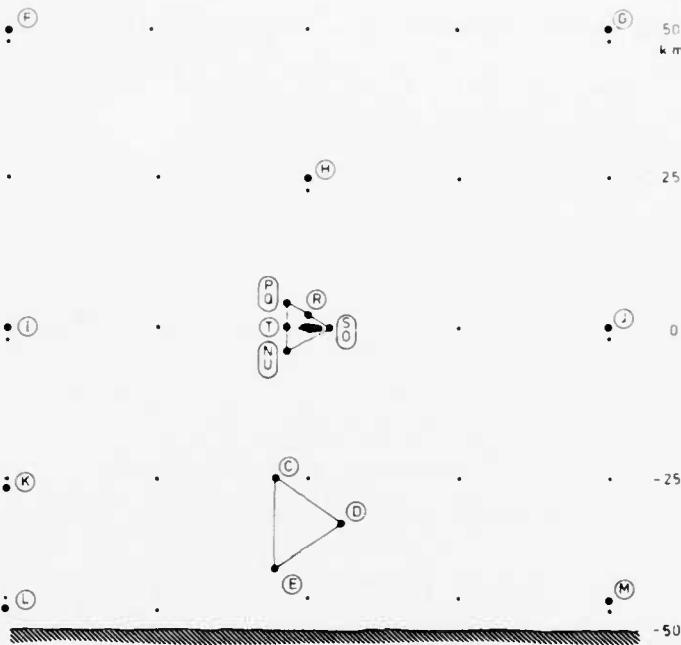
4.4. 1983 experiment

The experiment in the summer of 1983 will have several purposes.

- It will provide observations of temporal and spatial scales of several of the processes to be studied so that the different arrays (see Fig. 6) and the measurement plan for the 1984 experiment can be optimized. The observations include ice kinematics and deformation rates; ablation and transport measurement of the thermal balance in and immediately around the ice; ice concentration, ice types

and floe size distribution; energetics, structure and propagation of ice-ocean eddies; frontal characteristics; internal waves and fine structure; ocean and atmospheric boundary layer fluxes; acoustical and biological characteristics.

- It will provide observations, some of them mentioned above, needed for the ongoing atmospheric-ice-ocean modeling effort.
- It will test measurement concepts and systems such as the ice deformation array in a highly dynamic region; ice-ocean eddy in



- C-P Argos positioned buoys.
 C,D,E Bergen Toroid (air temperature, wind, current, sea temperature, conductivity. C has atmospheric pressure).
 F,M Bergen Ice Drifters (atmospheric pressure on F).
 G-L BIO Ice Drifters.
 N Cyclesonde UW/Miami (current, sea temperature, conductivity).
 Q Cyclesonde Miami (same sensors).
 O Temperature conductivity chain, UW, current.
 Q-U CRREL Del Norte Radar transponders (Q is master).
 • Radar corner reflectors.

Figure 6. Arrangement of drifting buoys.

situ tracking techniques in a difficult environmental region; internal waves and fine structure arrays; new application of the CODAR radar for surface current observations and of the Cyclesonde for profiling current, temperature and salinity from the drifting ice; flux measurement arrays in the boundary layers; testing of active and passive remote sensing techniques such as the SAR for tracking the ice edge structure, ice-ocean eddies and fronts and evaluation of methods and algorithms for deriving ice concentration, ice types and floe size distributions during summer time.

- It will test methods for real time processing of remote sensing observations with down-link from the aircraft to the ships. Together with real time processing of in situ observations and application of predicting schemes of, for example, ice drift and deformation, this will aid in controlling and optimizing the measurement plan, so that tactical rules for

the deployment of ships, drifting buoys, and aircraft can be prepared for the 1984 experiment.

The 1983 program will take place from early June to early August, a 60-day period. The platforms we will be using are the ice-strengthened ice-breaker R/V *Polarbjorn*, for the full period, equipped with two helicopters, and the icebreaker R/V *Polarstern* and the ice-strengthened R/V *Lance* for part of the period. The remote sensing aircraft will be the Canadian CV580, U.S. NRL P3, Danish C130 and ARA Baron.

This 1983 program, together with the ongoing modeling effort, will give us a better background of spatial and temporal variability associated with the different processes, which will enable us to improve our experimental design and measurement plan for the summer 1984 experiment as well as give us the opportunity to improve our instruments. It will also acquaint many participating scientists with the complex environmental conditions in the MIZ.

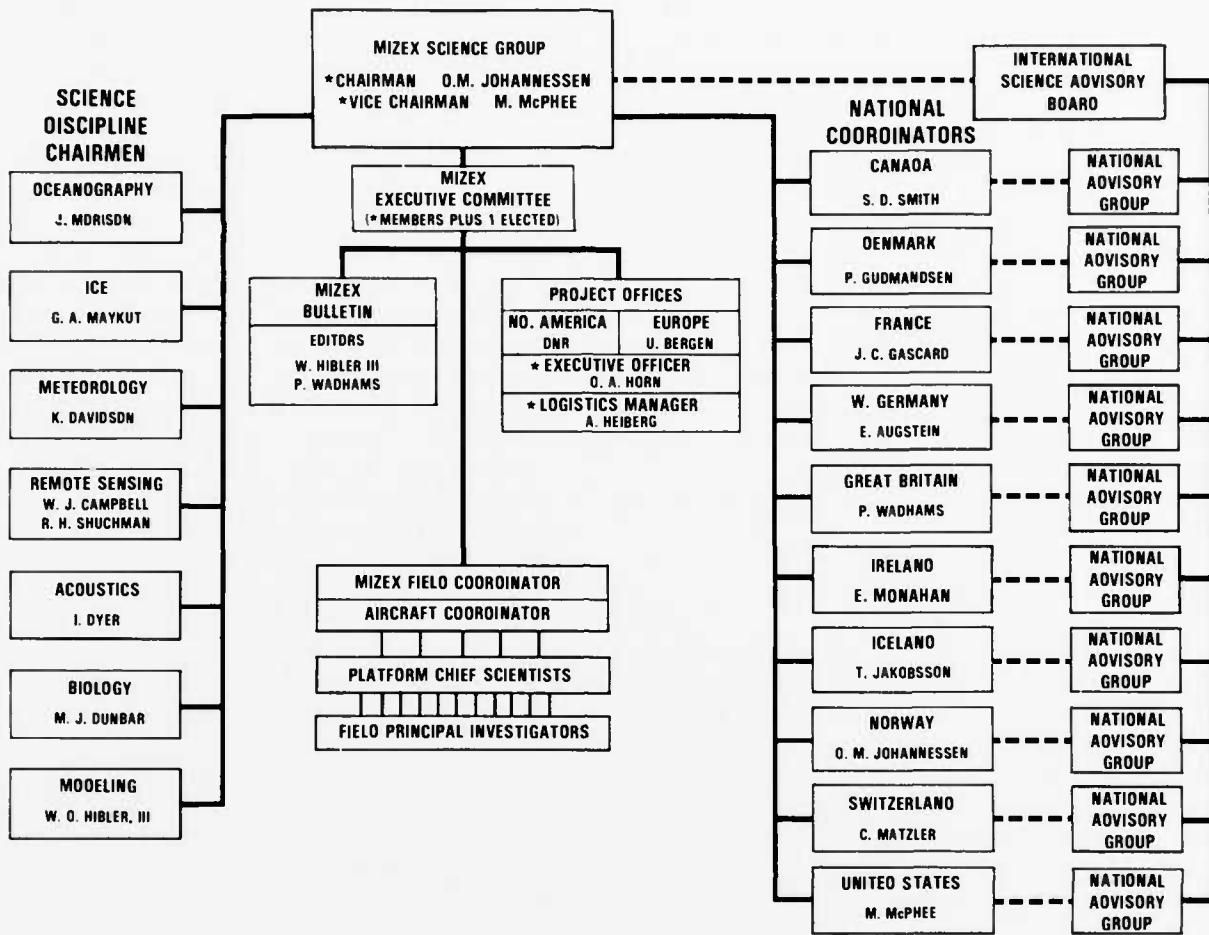


Figure 7. MIZEX organization.

4.5. Coordination

4.5.1. Initial coordination structure. In order to initiate a research strategy for the MIZEX program and to carry out initial planning for the 1983 and 1984 experiments an ad hoc MIZEX coordinating committee was formed in February 1981. As of September 1982 this group consisted of the following members (in alphabetical order):

W.J. Campbell	U.S.A.
M. Dunbar	Canada
I. Dyer	U.S.A.
K. Hasselmann	Fed. Rep. of Germany
W.D. Hibler, III	U.S.A.
O.M. Johannessen	Norway
P. Wadhams	Great Britain

Part of this group (with input from Seelye Martin on the Bering Sea MIZEX program) compiled an initial research strategy report (Wadhams et al. 1981). This report laid the foundation for the mesoscale experiments presented in this document which represents input material from more than 60 scientists from eight nations.

4.5.2. International coordination structure. To coordinate the MIZEX program an international science group has been set up with the structure shown in Figure 7. This science group consists of the national coordinator from each of the ten countries involved, together with the science discipline chairmen. The number of national coordinators may increase if more countries desire to participate in the program. An executive officer for the program has also been established. The executive officer is located at the U.S. project office for the program at the Office of Naval Research in Arlington, Virginia. The logistic manager is located at the Polar Science Center, University of Washington. A European MIZEX Project Office has been established at the Geophysical Institute, University of Bergen, Norway. A MIZEX Newsletter containing news of meetings and other information will be issued periodically.

To provide a permanent medium for the rapid interchange of initial results, data reports, and preprints of journal articles a MIZEX bulletin se-

ries will be issued. These bulletins will be published as CRREL Special Reports under the general supervision of a technical editor at CRREL, with the first two bulletins consisting of the MIZEX-1 report (Wadhams et al. 1981) and the present report. Copies of these bulletins may be obtained by writing to CRREL, Attention Technical Information Branch. Since this bulletin is basically a preprint series, inclusion of articles here will not preclude later journal submission. Authors wishing to submit articles or information to this series may send manuscripts with figures reproducible in black and white to either W.D. Hibler, III, at USACRREL or Peter Wadhams at Scott Polar Research Institute. Proofs of the retyped manuscripts will not be sent to the authors unless specifically requested.

5. COLLATERAL PROGRAMS

Appendix A of this document describes in detail the proposed ice, ocean and atmosphere experiments and the remote sensing program designed to resolve the physical processes that are important within the MIZ. The MIZ is, however, also an acoustical and a biological environment. An acoustics program addressing propagation, forward scattering, bathymetry, seismic reflection and refraction will be integrated into the MIZEX 1984 experiment, using the same platforms and taking advantage of the environmental parameters obtained by the MIZEX investigators. The potential usefulness for the MIZEX investigators is that the acoustic techniques can be used for synoptic measurement of MIZ oceanographic processes and mapping of ice characteristics. The acoustics program is described in full in an associated document by Dyer (1982), but its relevance to general MIZEX needs is discussed in Appendix B of the present document. MIZEX also provides a unique platform for studying biological processes in a region where very little work of this type has been carried out. Appendix C presents the background need and concept for the MIZEX biological program.

The MIZEX-1 report of June 1981 gave an outline of proposed MIZ investigations in the Bering Sea to parallel those in the Greenland Sea. A separate document entitled *Field Plan for the 1983 Bering Sea MIZ Winter Ice Deformation Experiment* coordinated by Seelye Martin, University of Washington, Seattle (Martin 1982), gives further details of experiments which took place in February 1983, to study this different type of MIZ

where thin first-year ice lies over shallow water with little velocity shear. The experiment concentrated on ice advection, deformation and ablation. Communication is well established between investigators in this experiment and investigators in the MIZEX summer experiment in the Fram Strait-Greenland Sea and several MIZEX principal investigators are participating in both experiments, using similar experimental techniques.

The proposed Fram Strait Monitoring Program, mentioned in the *Executive Summary*, is designed to monitor the heat and mass transports through Fram Strait over a 5-year period. Plans call for 25 current meter moorings with 125 current meters to be deployed across the strait, some under the ice, while the ice export will be monitored by Argos-tracked buoys placed on the ice (20 per year). Other buoys would monitor the upper ocean and atmospheric pressure, while ice thickness would be measured by impulse radar. Several CTD sections across the strait will be carried out each year as well as remote sensing flights. Clearly there is great potential for symbiosis between the Fram Strait Project and MIZEX.

A proposed Antarctic ice margin program, AMERIEZ (Antarctic Marine Ecosystem Research at the Ice-Edge Zone), is currently being initiated. This program, which will be particularly relevant to MIZEX (see, e.g., Slinn et al. 1982), will concentrate on biological processes near the ice margin, and has a first icebreaker cruise planned for November 1983.

A summer ice remote sensing program, FIREX/RADARSAT, has been conducted and will be useful for the planning of both the MIZEX 1983 and 1984 experiments. The objective was to determine the microwave backscatter and emission coefficients of Arctic interior summer ice for analysis of SEASAT, NIMBUS and other historical data sets and for algorithm development for future missions.

Finally, of course, MIZEX is complementary to the ASI Program described in the associated document by Untersteiner (1982), and every effort will be made to ensure that MIZEX results are used fruitfully in the development of ASI aims.

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APPENDIX A: DETAILED PLAN OF THE AIR-ICE-OCEAN EXPERIMENT

A1. SEA ICE

The main purpose of the sea ice program is to characterize and understand the sea ice processes occurring in the MIZ. The approach in achieving this goal is to intensively measure the ice drift and deformation, ice growth and decay, and physical properties in a region near the ice margin. In a first analysis, these properties will be mainly correlated with ice floe size and thickness characteristics. More complete analysis will require combining ice data with data obtained by the oceanographic, atmospheric and remote sensing programs.

In the following subsections an experimental plan for measuring the most important sea ice characteristics is presented.

A1.1. Ice dynamics and kinematics

Ice dynamics field studies will be carried out in two zones: the extreme ice edge within a few kilometers of the edge, and an interior region nominally 30 km into the ice. This distance was chosen to be representative of the location where the floes become significantly larger than right at the margin, and where the effect of wave action on ice floes has been significantly reduced.

Data from these experiments will be analyzed to characterize both the ice kinematics and the ice dynamics. In examining the kinematics particular emphasis will be placed on determining the spatial and temporal variations in the ice velocity field. With regard to ice dynamics, the kinematic information will be used in conjunction with model simulations, floe bumping data, and floe size characteristics to deduce the characteristic nature of the ice rheology in the MIZ. This information will aid in constructing models to simulate the ice drift and deformation, which, when combined with thermodynamic models discussed later, will aid in describing the retreat of the summer ice edge.

A1.1.1. Interior ice dynamics and kinematics

Objectives. The objective of the interior ice dynamics study is to characterize the ice kinematics and ice dynamics on scales of 10 to 30 km in a region close (< 50 km) to the ice margin and to determine to what degree ice dynamics modify the air-sea momentum exchanges, and indirectly the heat exchange. To meet this objective, a four-component field study will be carried out: 1) deploy and monitor a six-unit transponder array spanning approximately a 20-km-square region; 2) deploy and monitor at least two accelerometers which measure collisions between ice floes; 3) carry out low-level mapping missions over the transponder array using a 70-mm aerial survey camera strapped to a helicopter; 4) deploy a rosette of three strainmeters near the ship to measure flexure of the floe moored to the ship.

Description of experiments. 1) The transponder array will be deployed in the configuration shown in Figure A1 using helicopters from the ship in the ice. The main array consists of eight Del Norte microwave transponder units. Two of these units (designated Master Remotes) will be capable of measuring distances to other remotes by "range loop" methods. This allows the X-Y position of each unit relative to a reference line to be monitored with an accuracy of about 5 m. Measurements will be made automatically at 2-hr intervals, so that higher frequency motions such as inertial oscillations can be measured. To determine the rotation and absolute position of the array, radar transponders discernible on the ship's radar (Vega or Motorola transponder) will be deployed at master remote sites. These have a lower resolution than the Del Norte system, but this will not degrade the accuracy of the strain rate deformation time series. The batteries for these units will be replaced once a week, and any destroyed units will be replaced.

2) The accelerometers will be deployed on selected floes using helicopters within the deforma-

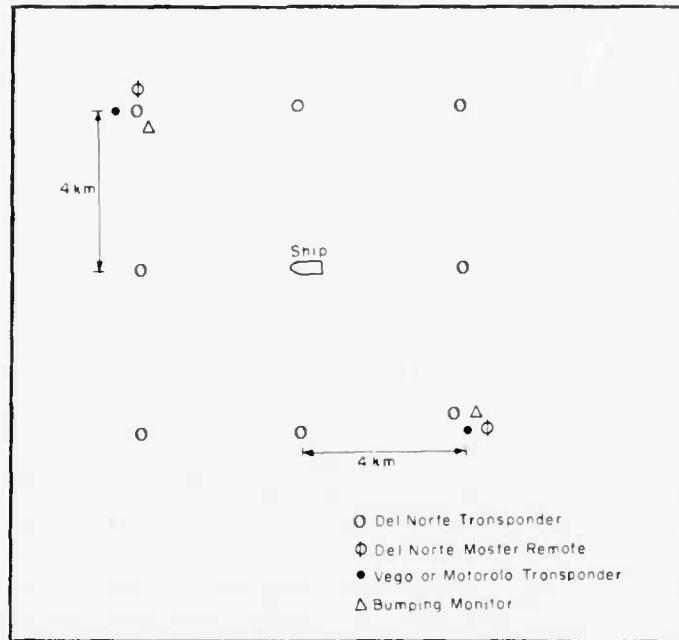


Figure A1. Schematic of interior ice dynamics array.

tion array and will telemeter a coded signal back whenever a bump due to horizontal acceleration occurs. In addition the rotation of the floes and the heave due to waves will be monitored using a compass and vertical accelerometers. The positions of these floes will be marked by dye, and the instruments will be serviced when the need arises, probably at about two-week intervals.

3) The low-level mapping mission will be carried out using a 70-mm aerial mapping camera strapped to a helicopter. The flights will use the method successfully employed during the YMER expedition to monitor floe size characteristics. Specifically, the helicopter, equipped with a radar transponder, flies on a constant bearing at 1600 ft and is tracked on a ship's radar with the time and position recorded. Pictures are taken at 5-second intervals, with the time noted by a synchronized watch on the helicopter. The main characteristic to be observed is the floe size distribution, but the photographs also allow characterization of the open-water fraction and floe geometry.

4) To monitor floe flexure, a rosette of three strainmeters will be attached to the floe near the ship during periods of aroused sea state. These strainmeters allow the magnitude and direction of swell to be monitored. The hope here is that the flexure can be monitored during actual floe break-up, which will be especially useful for verification of wave-ice interaction theories.

A1.1.2. Extreme ice edge dynamics and kinematics

Objectives. 1) If a large ice-water eddy is present, to map the ice motion within it, including the random component. 2) In the absence of an eddy, to monitor the ice kinematics in the extreme ice edge region, including the formation and motion of bands. 3) To monitor the direct and reflected wave spectrum at the ice edge, especially during times of band formation.

Description of experiments. 1) The main problem here is to identify the presence of a large (60-km) eddy, since it may not be clearly visible as a whole on a ship's radar or by observation from a helicopter. One method is to have a satellite image received aboard the ice edge ship, although here success depends on clear visibility. Another method would be to have some means of transmitting real-time remote sensing imagery from appropriate aircraft to the ship; one way of doing this with SAR/SLAR is described in the remote sensing section.

Once an eddy is identified, a helicopter is used to deploy four radar transponders within it, each with a radar reflector as back-up in case of power failure (Fig. A2a). The transponders are tracked on ship's radar. If the ship has an excellent positioning system (i.e. global positioning system or else satellite navigation updated by Omega—satnav alone is inadequate) then it can carry out CTD

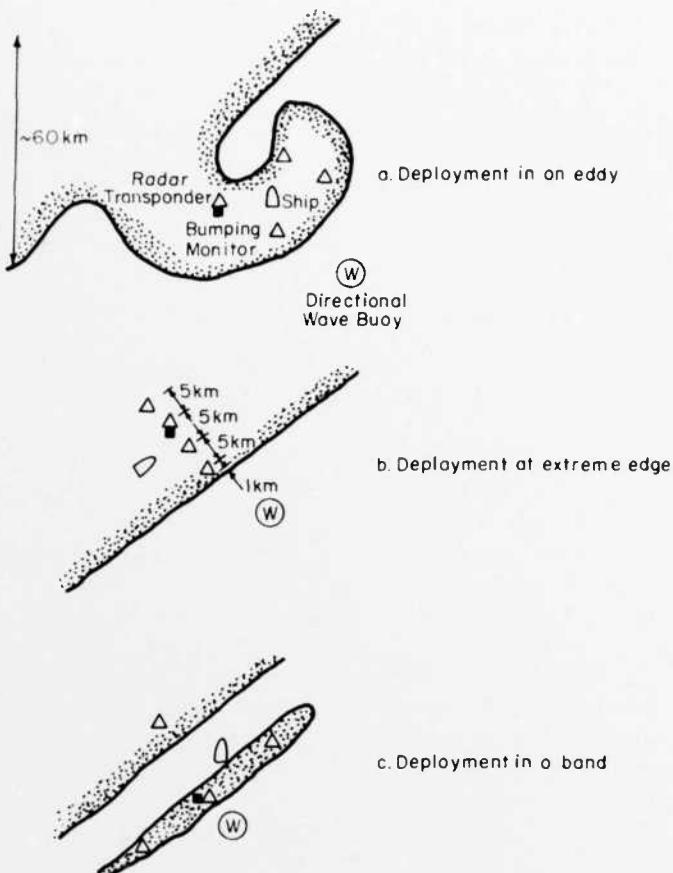


Figure A2. Extreme ice edge transponder configuration.

mapping (see Section A2.1.2) of the eddy simultaneously with fixing of the transponders. A Radar Image Display System (IDRIS) has been developed to display and record marine radar data, and to display radar imagery produced by aircraft and transmitted to the ship by a downlink. The prime use of this system will be to track ice features and transponders using the ship's radar, with the advantage of recording all of the data for further analysis. The system digitizes ship's radar in real time and converts it to a color x-y image. Features can be tracked in automatic or interactive modes. If ship's position data are available the system can provide real-time motion vectors for features and transponders within the radar's range.

A bumping monitor (a telemetry array consisting of vertical accelerometer, two-axis horizontal accelerometer and compass) is also deployed at one of the transponder positions to monitor mean free path. While tracking is being done, the helicopter flies a grid of track lines from 1600 ft with a 70-mm survey camera to sample the ice and floe

size distribution within the eddy. The eddy is tracked until it disperses. Frequent repositioning of the transponders (about once per day) may be necessary to keep all four within range of ship's radar, and the helicopter mapping (2-3 hours flying) should be repeated daily.

2) In the absence of an eddy, the four radar transponders are now deployed in a line normal to the ice edge at 5-km intervals, beginning 1 km from the edge. The bumping monitor (or "collidoscope") is placed at the third site from the edge (Fig. A2b). Tracking is carried out for as long as the ship can remain in the area, with helicopter coverage as in "1" above. It is important that wind speed and direction be continuously recorded from the ship during these observations. It would be helpful if the thickness of typical floes could be measured by the ice properties team (Section A1.2.3). If a band begins to separate from the ice edge, two or three radar transponders are placed on it (leaving one in the main pack) and tracked, while intensive floe size/band shape mapping is done by helicopter and a series of CTDs

done to seaward and iceward. The collidoscope is placed in the band to monitor local wave field while the Wavetrack buoy (see Fig. A2c) is repositioned immediately to seaward of the band.

3) The ice edge ship deploys a Wavetrack directional wave buoy just outside the ice edge at the beginning of the experiment, and remains within telemetry range of it throughout, repositioning as necessary. This measures the wave field incident on the ice edge and, together with the bumping monitor in the interior array, measures the wave decay rate across the MIZ.

A1.2. Ice growth and decay studies

The ice growth and decay experiments will be carried out on a number of scales, ranging from that of a single floe to that of the entire experimental area. The general aim of the summer experiments is to understand the rate and nature of the ice decay processes as an element in the thermal budget of the MIZ. In addition, the characterization of ice properties is a service for other parts of the MIZEX project, e.g. the ice dynamics program, the atmosphere and ocean boundary layer program, and the remote sensing science program to determine microwave signatures. Special attention will be paid to the area enclosed by the transponder array around the drifting ice station.

A1.2.1. Small-scale monitoring

Objectives. The primary objectives are to: 1) obtain detailed information on the role of the upper ocean in the decay of the ice cover, 2) gauge the importance of atmosphere-ice interactions relative to those between ocean and ice, 3) identify and quantify the processes which control the transport of heat from the water to the ice, 4) estimate the input of heat and meltwater to the ocean, and 5) quantify temporal and spatial changes in the state of the ice cover and the effects of such changes on the rate of ice decay and retreat.

Description of experiments. The basic plan is to instrument a typical floe in the MIZ and monitor mass changes occurring at the top, bottom and sides of this floe. All energy fluxes which transfer heat directly between the ice and the atmosphere will be determined. Shortwave radiation absorbed in leads surrounding the floe will be measured and resulting changes in heat content of the upper ocean observed. Oceanic heat flux at the bottom of the floe will be deduced from bottom ablation and compared with changes in heat content of the water column below the ice. A small area (1-2 km on a side) will be photographed daily from one of the ship's helicopters to provide detailed informa-

tion on erosion and floe breakup not available from other remote sensing data. The photos will also be used to map changes in melt pond coverage and ice concentration near the ship, data which are needed for estimating total meltwater runoff and solar heat input to the ocean.

The specific field measurements include:

- i) surface ablation in areas of bare ice, snow-covered ice, melt ponds, etc.
- ii) bottom ablation in a line perpendicular to the floe edge and at 8-10 other locations randomly located across the floe
- iii) lateral ablation at 10-12 locations around the periphery of the floe
- iv) horizontal and vertical profiles of temperature and salinity in leads adjacent to the floe
- v) surveys of melt pond coverage and surface water storage
- vi) sequential aerial photography of the area
- vii) periodic albedo (total and spectral) surveys of all available surface types
- viii) net radiation balance over selected surface types
- ix) internal ice temperatures to obtain conductive heat fluxes in the ice.

If a suitable pressure ridge is available, it will be instrumented in order to compare ablation in areas of deformed and undeformed ice. Tracer dyes will be used to look for organized convection patterns in leads. A particular effort will be made to differentiate between mechanical erosion and direct melting on floe edges. Salinity and temperature measurements in the leads will be concentrated in the upper 5 m, but a few deeper points will be observed for comparison with the CTD values obtained beneath the floe as described in Section A2.2. Spectral extinction coefficients in the ice and water will be measured near the beginning and end of the experiment. An aerial survey of surface temperatures in leads using a helicopter-borne PRT-5 radiometer will be carried out a few times during the experimental period. To attain the objectives listed above, the data analysis needs information from the mixed layer studies and the meteorological program. Remote sensing data on the state (ice concentration, floe size distribution) of the ice cover are needed for extending the small scale results to larger space scales.

A1.2.2. Mesoscale monitoring

To understand the heat balance of the experimental area as a whole, it is necessary to measure the bottom ablation and its gradient, and the tem-

poral variation of the ablation, in a systematic way across the MIZ during the entire experimental period. Because ice dynamics, upper ocean dynamics and ice ablation are a coupled system the ablation program will be closely coordinated with the oceanographic and ice dynamics programs with regard to site selection and simultaneous instrument deployment. In this manner the data from each program will be complementary.

The measurement of bottom ablation and its gradient will require the placement of five ice thickness sensors in a line normal to the ice edge at sites occupied by either the ice dynamics program or the oceanographic program. However, each sensor is self-contained and may be placed individually at suitable sites. Each sensor consists of an upward-looking sonic transducer that is mounted below the ice. The change in travel time of the sonic pulse between the transducer and ice bottom gives a direct measurement of the ablation or accretion rate. The data will be both internally recorded and telemetered back to the ship.

Ablation sensor deployment and servicing, approximately every two weeks, will take place in conjunction with deployment and servicing of other instruments; hence, only a small amount of additional helicopter time will be required. Sites only occupied by an ablation sensor will require 4 hours of helicopter time for deployment and redeployment, with 1 hour for sensor servicing.

Studies of ice edge phenomena, bands and streamers also require bottom ablation measurements. To accomplish this, a master station will be deployed along with other instrumentation from the ice dynamics study; in this manner only a small amount of helicopter time will be required. CTD casts near the feature being studied will supply supplemental data. For a band study, casts at the leading and trailing edges of the band will be required.

A1.2.3. Ice properties and local morphology

To examine the ice properties and local morphology, an ice properties team will be aboard each of the ice-going ships. Their program will include microscale ice structure examinations, chemical and possibly biological studies through the collection of sea ice cores, and local studies of ice morphology and ridging. The intent is to collect ice cores at various locations and further towards the Greenland coast while carrying out the morphology studies at these same sites.

The teams will be flown by helicopter to predetermined sites where cores and morphological studies will be carried out. Photographs of the

sampling sites and the surrounding ice (approximately 0.5 km radius) will be taken from the helicopter deploying an aerial mapping camera for later correlation with the morphological descriptions. Several cores (3 to 4) from different types of ice will be taken at each sampling site through the entire thickness of the floes. In situ processing will include temperature profiling, density profiling and core logging. On-site morphological studies will include thickness measurements and ice type descriptions of floes within the sampling area. First-year and multi-year pressure ridges will also be investigated with regard to length, width, height and keel depth. Sail measurements will be made using surveying techniques, and keel depths assessed by lowering a horizontal-looking sonar adjacent to the ridge. Further measurements on first-year ridges will include block size distributions and the percentage of void space (porosity) contained in the ridge sail.

If adequate freezer space is available some core analysis can take place on the respective ships. This will include longitudinal division of the core, salinity analysis, and preparation for thin-section analysis.

A1.2.4. Ice thickness distribution

However extensive the ice morphology program, it cannot give a very accurate picture of the overall distribution of ice thickness throughout the MIZ. This function, and its variation with downstream distance, with distance from the ice edge, and with time, is extremely important for heat and mass budget calculations. The best way to obtain this knowledge reliably is by submarine sonar profiling. Manual methods (hole drilling) are prohibitively laborious and do not yield a statistically valid sample, while other surface sensing methods such as impulse radar sounding have not yet been developed to the point where they work reliably for sea ice. The only above-surface method of real usefulness is airborne laser profiling (Hibler 1975): it is useful in itself for yielding top surface roughness for boundary layer analysis, and as a result of comparative laser-sonar studies (e.g. Wadhams 1981) it is now possible to infer a great deal about the ice thickness distribution from the results of laser profiling.

It is hoped that a naval submarine can be deployed within the experimental area. It would be equipped with an upward-looking sonar, a sidescan sonar to give information on the spatial structure of bottom roughness (Wadhams 1978) and a sound velocity or conductivity-temperature sensor to record water structure across the polar

front. It would run a grid of profiling lines across the experimental area, with special concentration on the area of the ice deformation experiment where perhaps its track can be guided by transponders inserted through the ice. On a larger scale it would be of tremendous benefit to have a series of sonar transects across the entire width of the East Greenland pack ice at various latitudes, with a connecting longitudinal line, to assess the downstream progression of ice characteristics; this need not take place simultaneously with the meso-scale experiment.

If a submarine is unavailable, we will employ a mix of laser profiling, inference from ice properties surveys and remote sensing imagery, and (it is hoped) deployment from a low-flying helicopter of an improved design of radar ice sounder now under development.

A2. OCEANOGRAPHY

Oceanographic investigations will focus on fronts, eddies, mixed-layer dynamics in the ice edge region and ice edge upwelling if it occurs. Modeling of the above-mentioned phenomena in MIZ are either underway or being initiated. The model results as well as the results from the proposed pilot program in the summer of 1983 will be used in the final design of the 1984 experimental plan.

Since fronts, eddies and upwelling all require a well coordinated time sequence of three-dimensional synoptic mapping, they will form one part of the oceanography program (Synoptic MIZ Mapping). The oceanic mixed-layer study in the ice edge region will form a second part (Ocean MIZ Mixed Layer Study). The third and last part of the program will be a spatial study of the internal waves and vertical fine-structure in both the ice edge region and off the ice edge, so that a comparison can be done (MIZ internal waves). These three programs are discussed in greater detail below.

A2.1. Synoptic MIZ mapping

A2.1.1. Objectives

1) To describe the three-dimensional structure of the fronts (East Greenland polar front and meltwater fronts) in the Fram Strait-Greenland Sea MIZ, their short-period (days) temporal and spatial variability, including such processes as instabilities, eddy shedding, associated fine-structure and the relationship between the fronts, the ice edge and bathymetry.

2) To describe the characteristics of the eddy field in the MIZ, its space and time scales, energy level, possible generation mechanisms, propagation and the role of eddies in lateral heat and mass exchanges in the MIZ.

3) To describe how upwelling along the ice edge relates to the wind-stress variation across the ice edge.

A2.1.2. Experimental plan

Synoptic studies of fronts, eddies and upwelling in the MIZ demand a well coordinated measuring plan. The presence of the ice pack causes considerable logistical constraints and will slow down the sampling rate. Real time analysis is required to locate and track eddies as well as to discover upwelling events when they occur.

To study the above-mentioned phenomena requires a time sequence of three-dimensional synoptic mapping of the scalar and the velocity fields, as well as the atmospheric forcing fields. We will first outline the different measuring systems to be used before the observational plan is discussed.

Measuring systems. The scalar fields, temperature, salinity and density will primarily be mapped by use of CTD systems (Neil Brown) from all the ships. Helicopters will also take part in CTD mapping (ODEC-CTD) (Hunkins et al. 1979). In the open water off the ice edge remote sensing techniques will be used for surface temperature, supplemented by AXBT drops in a grid pattern. SAR-SLAR radars will be used for mapping of the ice edge location and structure, and surface expression of eddies, fronts, and internal and surface waves. The velocity field will be measured by current meters (Aanderaa and VACM) and by Cyclosonde profilers, some moored and others suspended from the drifting ice. In the open water off the edge, surface current will be observed by a CODAR system at selected times. The CODAR system consists of two elements to be located on the ships in the ice with a typical baseline of 50 km. Argos and RDF-tracked drifters located in the upper and lower layer will be deployed, as well as free-falling velocity probes at selected times.

Grid design. In the northern region, area 1 (Fig. 1), the grid will cover an area approximately 100-150 km along the ice edge, starting 40-50 km off the ice edge and extending 40-50 km into the pack. The drifting ship, with the ice deformation and the ocean mixed layer arrays, will be located in the eastern part of the grid when the synoptic mapping starts. As repeated mapping takes place the ice ship will drift with the ice pack through our fixed grid in 15-20 days, and provide observations

of ice drift, current and meteorological parameters. Our grid is fixed in space with gridlines directed perpendicular to the ice edge, spaced 5–10 km apart with CTD station spacing 2–5 km apart. This spacing is necessary to resolve the eddies in this region which have a 10–15 km scale.

One complete mapping using two ships in the open water and two ships in the ice assisted by two helicopters for CTD dippings will take approximately 2–3 days, depending on weather and ice conditions. Grid point distortion due to ocean advection and the slow-moving ships will be corrected by applying a Space-Time Objective Analysis scheme (Carter and Robinson 1981). AXBT mapping in area 2 (Fig. 1) will be coordinated with the CTD mapping in area 1 (and vice versa), so that the synoptic temperature fields for the Fram Strait–Greenland Sea MIZ will be mapped simultaneously.

In the open ocean off the edge we plan to moor 8–10 subsurface current meter strings for the whole experimental period. Several array patterns for these current meters are presently under discussion, from triangular arrays to line arrays perpendicular to the ice edge. In this region during summer time we have a typical two-layer situation, with the upper layer thickness in the order of 15–20 m. It will therefore be difficult to deploy moored current meters in the upper layer using subsurface floats. Surface mooring will contaminate the current meter record. In the open ocean off the edge current measurement in the upper layer will primarily be based on deployment of Argos and RDF drifters, and free-falling velocity probes in selected patterns. In contrast to the open ocean the ice pack is a very convenient platform from which current meters will be suspended (Section A2.2.2). However, one disadvantage is that the drifting ice platform excludes Eulerian information.

Eddy tracking. It is predicted that the ice drifting ship will drift through the northern area in 15–20 days. This should enable us to perform at least 3–4 complete CTD mappings, and some dedicated eddy tracking of one or two selected eddies. When an eddy is located, e.g. after the first synoptic CTD mapping or from remote sensing observations, “star” pattern CTD sections will be carried out, and drifters will be deployed in the eddy. Free-falling velocity probes will be dropped and the surface current determined by the CODAR system. If the eddy is shed from the ice, transponders initially located on the ice within the eddy region will be tracked by the ship (Section A1.1.2).

Upwelling. If upwelling should occur along the ice edge, the ice-strengthened ship will be dedi-

cated to study this event and will carry out frequent CTD sections perpendicular to the ice edge, deploying Argos and RDF drifters within and outside the upwelling region. A second ship will work along the ice edge in the upwelling region, to investigate the three-dimensional character of the event, using CTD supplemented by AXBT drops.

When the ice-drifting ship has drifted through the synoptic mapping grid, the second area in the East Greenland Current region will be investigated, using the same procedures as in the northern region. AXBT mapping will already have been carried out. Several current meter rigs will already have been deployed before the experiment started in the North. Present plans call for a triangular array anchored between 77°–78°N and in the 500- to 1000-m isobath region, in particular to test the hypotheses concerning dynamic instabilities associated with the East Greenland Polar Front.

It is stressed that this is our first version of a measurement plan. It will continue to develop into a more precise plan aided by information from the program in MIZEX 1983, modeling results and ongoing analysis of recent experiments such as NORSEX (Johannessen et al. 1983) and MIZ LANT (Paquette 1982).

A2.2. Ocean MIZ mixed layer study

A2.2.1. Objective

Our objective is to study the structure and dynamics of the mixed layer and upper ocean in the marginal ice zone. We are especially interested in determining the surface fluxes of heat, salt and momentum as functions of ice velocity, ice concentration, floe size, current structure and atmospheric forcing. Measurements of these parameters are vital to an understanding of the coupling between the ocean and the ice under conditions unique to the MIZ.

A2.2.2. Experimental plan

In order to study the spatial variations in the mixed layer and upper ocean, an array of devices measuring salinity, temperature, and velocity will be positioned in the marginal ice zone. The largest gradients in the measured parameters are expected to be in the cross-ice-edge direction, so the array will be arranged to provide more resolution in the cross-edge direction. We plan on deploying five cross-edge elements which include two Cyclesondes at 8-km spacing iceward of the drifting ship, the Arctic Profiling System (APS) making vertical profiles of temperature, salinity and velocity to 200 m every 20 minutes near the drifting ship, and two Cyclesondes seaward of the drifting

ships. To the degree possible, these Cyclesondes will be located at ice transponder sites (Fig. A1). ARGOS buoys with conductivity-temperature strings to 100 m are located 16 km up-and downstream from the drifting station to document the along-ice gradient in temperature and salinity. Collocated with each of these will be strings of internally recording current meters. The Cyclesondes are to be located by the use of the ice strain transponders and by ARGOS positioning. They report data by VHF radio and also record internally. The devices are described in Van Leer (1980). The APS is a wire-lowered device capable of high-speed profiling (Morison 1980). The conductivity temperature chain buoys are described in Morison and Burke (1981).

In addition to measuring advection and the spatial variation in mixed layer structure, the array will permit the examination of the Ekman boundary layer beneath the ice, the shear at the base of the mixed layer, and the deeper advection of warm, salty Atlantic water. Richardson number profiles and tidal and inertial motions, as well as daily average geostrophic currents, may be computed.

Second, the turbulent boundary layer will be studied and direct measurements of Reynolds stress will be made using triplets of high-accuracy, high-frequency response current meter probes mounted on a rigid mast below the ice. The measurements will be made at the drifting station in conjunction with APS profiles. The latter will be used to make continuous determinations of stratification and velocity. The APS velocity profiles will also be used to make direct measurements of the total stress due to turbulence and form drag using the momentum integral technique.

Direct measurement of the surface fluxes of heat and salt will be made by personnel at the drifting station studying ice ablation. The partitioning of momentum flux at the surface of leads and polynyas into turbulence and wave generation must also be examined. It is believed that much of the stress going into wave generation is ultimately transferred to the ice through radiation pressure. In addition, much of the wind stress may be transferred laterally by the ice interaction. Theoretical investigations of this process will be carried out and any need for special observations during MIZEX will be assessed. Analysis of the data will proceed in conjunction with the ice dynamics study.

It is most important that the functional dependence of the surface fluxes on ice concentration, floe size, and atmospheric forcing be determined.

Therefore, measurements of these parameters by the remote sensing and atmospheric groups are vital.

A2.3. MIZ internal waves and fine-structure

The MIZEX program offers the opportunity to investigate some fundamental questions on internal wave generation. The internal wave field can be monitored simultaneously under ice where there are essentially no surface waves and in the open ocean across the ice edge. Comparison of spectra should provide insight into wind wave effects on internal waves.

Furthermore, abundant vertical fine-structure (~10 m) and mesoscale (~100 m) structure formed by interleaving of Polar and Atlantic Water intrusions are observed in the marginal ice zone. Horizontal scales are on the order of 10 kilometers. We would like to know the role played by this intrusive structure in the exchange of properties across the front.

A2.3.1. Scientific objectives

1. How does the internal wave field differ under pack ice and in the open ocean?
2. What is the role of vertical fine-structure in the transfer of properties across the fronts?

A2.3.2. Experimental plan

Small-scale ice array: Simultaneous CTD profiles will be taken from a triangular network with a 1-kilometer spacing consisting of the drifting ship and two small ice camps. Sampling intervals will be 1 hour during special 24-hour periods coordinated through the entire oceanographic program and otherwise at less frequent intervals. Velocity fine-structure will also be monitored at the ship with a Neil Brown acoustic current meter. The network will be located on a single floe, if possible, to ensure dimensional stability.

An array of current, temperature and salinity recorders (Aanderaa RCM-5) will be suspended from the same ice floe at six sites chosen to monitor a wide range of internal wave frequencies and wave numbers since sampling will be at one-minute intervals. Suspension will be at fixed levels (5, 20, 100 and 300 m) in the mixed layer and halocline.

Small-scale, open-water array: Two arrays of current, temperature and salinity recorders (RCM-5) will be deployed in open water about 30 km outside the ice edge. Each array will consist of three bottom-moored instrument strings designed to closely parallel the ice arrays and will be situated so that the ice array will drift past them.

A2.4. Tracer studies

A2.4.1. Scientific objectives

- 1) Measure the isolation age of waters in the halocline.
- 2) Estimate the amount of air/sea exchange during the last few years.
- 3) Estimate the amount of ice freezing on the shelves relative to the total amount of water, i.e., the amount of brine added below the surface mixed layer.
- 4) Estimate the amount of sea level ice melt water in the water column.

A2.4.2. Experimental plan

Measurements of tritium and profiles of dissolved rare gas in the ice and water will be made. Also, alkalinity and the concentration of stable oxygen isotopes will be measured. To make these measurements, water samples will be taken at the drifting station and from the open-water ship. Rare gas extraction will be performed on board ship, but other samples will be analyzed on shore after the experiment.

A3. METEOROLOGY

One objective of the meteorological program is to give the field of stress and thermodynamic energy fluxes over the region which interacts with the ice edge. In order to specify these fields with a certain minimum accuracy specific routine measurements are needed.

We can make direct measurements of the fluxes only sporadically, at a few points. In order to develop the parameterization to furnish these flux values for the entire MIZEX domain, three types of measurement need to be made. First, measurements to establish the basic parameters at a point. Second, measurements of mean flow characteristics which can be used to employ the parameterization. Third, the basic mean surface measurements (pressure and temperature) which allow extensions of the flux parameterizations to the largest scales (synoptic).

The meteorology plan for the summer MIZEX experiment is presented in the following synoptic, mesoscale, and microscale programs. The synoptic scale covers several thousand square kilometers centered on the MIZEX area for the 6-week duration of the experiment. Mesoscale studies cover heights through the top of the PBL, horizontal scales characteristic of boundary layer modification (up to 100 km) and time scales ranging from

an hour to a day. Microscale processes of air-sea-ice interaction involve measurements at low levels (below 30 m) over horizontal scales of a few hundred meters, and over periods of one to two hours. Airborne and surface programs are coordinated to provide a description of air-sea-ice interaction processes on all scales and a basis for parameterizing and modeling atmospheric forcing of ice drift and growth, and the interaction between the marginal ice zone and the atmosphere.

A3.1. Synoptic scale meteorology

A3.1.1. Objectives

The main objective of the synoptic scale meteorology program is to provide a description of the synoptic scale weather conditions in the region of the ice edge, with the aim of relating these conditions to ice and ocean conditions in the marginal ice zone. To meet these objectives both a field measurement program and a forecast-analysis support program are planned.

A3.1.2. Experimental plan

Field measurement program. Standard surface observations will be collected at hourly intervals following WMO specifications by trained meteorological observers on all ships. These will include records of clouds and precipitation. All components of radiation fluxes will be measured. Pressure measurements will be obtained from an array of unmanned buoys. These meteorological observations will be coordinated with modeling studies to ensure that they provide a data base suitable for atmospheric and ice-dynamics modeling.

Aircraft measurements will complement the surface-based measurements by providing wind and temperature coverage of the large portion of the MIZEX area. Aircraft measurements are also planned as part of the mesoscale program. The aircraft remote sensing program is described in Section A4 of this Appendix. Measures have been taken to ensure that all relevant field observations are immediately entered onto the Global Telecommunications System (GTS) for subsequent use in operational forecasts.

Forecast-analysis program. During the field experiment, all operations will be greatly assisted by accurate weather analyses and forecasts. These will require forecasters on a ship with adequate communications equipment and at Tromsø. At present, limited forecast support for shipping and fishing operations is provided by the Norwegian and British Meteorological Offices, but these generally do not cover the MIZ. As a consequence,

enhanced forecast support has been sought for the field operations. This includes specialized forecasts from the national forecast centers, maintaining a field forecaster in the operations center at Tromsø, and arranging for specialized support from major modeling groups.

In addition to forecast support, there is a particular need for high quality objective analyses in the MIZEX region for use in both ice modeling studies and/or as an aid in interpreting field data. The combination of the objective analysis (with which the forecasts are initialized), the operational forecasts themselves, and the related diagnostics produced by the atmospheric model constitutes a very complete description of the atmospheric synoptic fields. These data will prove valuable in subsequent analysis of the oceanographic and ice data (e.g., the response of ice cover or ocean mixed layer to the passage of storms). The volume of data involved here is very large, and thus is not routinely saved.

To ensure that such high quality analyses will be available and to ensure that all available data are utilized in these analyses, we propose to institute a "special effort" data set enhancement program with an appropriate meteorological center. This approach will ensure that all available data for the MIZEX region will be archived and utilized in analyses. In addition it is hoped that "special effort" data set enhancements may be carried out similar to those done during the Global Weather Experiment (see Graves et al. 1979, *Bulletin of the American Meteorological Society*, vol. 60, p. 124). Here high resolution data sets were produced in special regions of interest by subjective evaluation of operational data that were augmented with finer scale observing systems. As an example, during the Global Weather Experiment, "special effort" analyses were produced for the western North Atlantic by selectively replacing satellite-derived temperatures in regions of obvious cloud contamination with those obtained using retrieval techniques tailored to the geographical location and the specific features of the cloud field.

A3.2. Mesoscale meteorology

A3.2.1. Objective

Mesoscale atmospheric features include development and modification of boundary layers due to passage across the MIZ, diurnally forced variations or other changes in surface stress, sensible heat flux, or evaporation, and local circulations. The objective of the mesoscale program is to pro-

vide a detailed description of these features using surface and aircraft measurements.

These data will yield an excellent study on atmospheric PBL modification in addition to furnishing information on local variations in surface stress and other fluxes.

A3.2.2. Experimental plan

Separate investigators will carry out mesoscale measurements from the open-ocean ship and the ice-drift ship. Three ships will launch radiosondes at frequent intervals during intensive observation periods.

A SODAR (acoustic sounder) will be used to continuously monitor the inversion height. To provide wind and stress variation across the MIZ, a mesoscale pressure array is needed. This would provide pressure gradients at two points, at least 100 km apart, and require at least three buoys with 0.1-mb accuracy on the ice and on the ocean. Boundary layer stratification evaluation requires air-sea temperature difference fields. Parameterization and verification of the mesoscale wind analyses require accurate point wind measurements.

A PBL investigation planned by the Alfred Wegener Institute for Polar Research will monitor the time variation of the vertical structure of the PBL in order to test one-dimensional prognostic numerical models and to study the processes relevant to PBL development. This will employ the Omega/Loran C wind system, Doppler SODAR and Radio Acoustic Sounder System measurements, and include surface heat budget measurements.

A study of the relationship between geostrophic and surface winds is planned. This will require surface wind measurement and accurate air pressure and temperatures at three points (buoys) of a triangular array to determine the geostrophic pressure gradient.

Whitecap coverage will be recorded photographically and later related to wind stress, aerosol concentration and microwave brightness temperature.

A long-range aircraft and a light aircraft flying from Spitzbergen will study mesoscale atmospheric circulation and wind stress in the vicinity of the ice edge, and will make low-level passes for comparisons with like data from open-water and ice-drift ships.

A3.3. Microscale meteorology

A3.3.1. Objective

The objective of the microscale meteorology

program is to measure the surface fluxes—wind stress, sensible heat exchange, evaporation and radiation—in a range of known conditions and to parameterize these fluxes in terms of drag, heat flux, evaporation coefficients and cloudiness, which are functions of ice type, wind speed, air and water temperatures, and humidity.

A3.3.2. Experimental plan

Near the ice-drift ship, wind stress, heat flux and evaporation will be estimated using "eddy-flux," "profile" and "dissipation" measurements. A 5-to 10-m-high portable mast will be set on the ice 50 to 100 m from the ship, with cables carrying data back to the ship. For comparison, dissipation method measurements will also be made at a carefully selected location at the bow of the ship, when the ship is facing into the wind. This method is considerably less vulnerable than eddy flux methods to errors introduced by airflow distortion around the ship, and shipboard measurements can be continued even if ice conditions are unsuitable for deployment of the mast on the ice, and so can provide data even in broken or loose pack ice.

To relate data from the mast on the ice to ice surface roughness, leveling lines along the upwind direction will be surveyed for up to 500 m. These will be compared with several airborne laser profile lines flown in the same direction and as close as possible (a few tens of meters) to the survey line. Comparisons will also be made with wind stress and heat fluxes measured by eddy correlation and indirect methods from aircraft flying several passes in the vicinity of the ice-drift ship. These microscale comparisons between surface and aircraft data will be valuable in interpreting the ice roughness and fluxes derived from the same aircraft covering meso- and synoptic-scale areas.

Dissipation method measurements of wind stress, heat flux, and perhaps evaporation from the "ice-strengthened" ship when it is operating in the ice margin will be obtained. The ship must stay on station with the bow into the wind during data runs of 20 to 60 minutes. A mast will occasionally be set out on the ice floes for direct eddy flux measurements.

Estimates of wind stress and surface fluxes at the open-ocean ship will rely primarily on established parameterizations. Measurements of wind, air and water temperature, and humidity at the bow of the ship are already included in the meso-scale projects and a log of visually estimated wave

height and period will be kept. Fluxes of solar and infrared radiation at the surface will be obtained at all three locations, and aerosols will be monitored from the open-water ship.

A4. REMOTE SENSING

A4.1. Introduction

Both active and passive, microwave and visible, remote sensing systems are proposed to be utilized during MIZEX. The sensors include: imaging radar (both SAR and SLAR), scatterometers, radiometers, laser profilometers, PRT-5s, AXBTs, aerial photography, CODAR, and dielectric constant measuring devices. These sensors are used either singularly or in combination, and have shown the ability to provide ice information which includes ice edge location, ice type identification, detection of gravity waves in the ice, ice morphology as a function of distance from the ice edge, location and aerial extent of melt ponds, ice roughness, floe size distributions, ice concentration, ice temperature, and ice dynamics. Ocean information that can be provided by remote sensors includes: ocean eddy and frontal mapping, gravity wave measurements, surface wind information, synoptic measurement of currents, sea surface temperature, and measurement of small-scale ocean surface roughness. Remote sensors have proven the ability to detect these geophysical parameters; however, the ultimate accuracy with which they can do so is unknown at present.

A4.2. Objectives

There are two overall objectives to the remote sensing program.

1. *Remote sensing as a service*—to provide baseline information on various ocean and ice characteristics required by MIZEX investigators, e.g. ice edge position, ice-ocean eddy location, positions of large leads and polynyas. This baseline information will be provided in near real time by SAR and SLAR aircraft. Other baseline information on the MIZ environment will be processed and made available after the experiment, e.g. surface wind and ocean wave spectral estimates.

2. *Remote sensing as a science*—to improve our knowledge of the microwave signatures of different ice types in summer. This will comprise the following elements:

- a. To develop improved algorithms for extracting geophysical ocean and ice parameters from aircraft and spacecraft (where

Table A1. Possible remote sensing aircraft and instrument ensembles.

<i>Aircraft</i>	<i>Nation</i>	<i>Instruments</i>	<i>Frequency (GHz)</i>	<i>Possible bases of operation</i>
1. CCRS CV-580	Canada	Imaging radar (SAR) Scatterometer Radiometer Aerial cameras	9.8, 5.3, 1.3 1.3 19.35	Tromso Svalbard
2. Falcon	France	Imaging radar (SAR) Photography INS winds	9.3	Tromso Bodo Svalbard Reykjavik
3. NOAA P-3C	U.S.	Imaging radar (SLAR) Laser profilometer Infrared profiler Reynolds stress 35-mm photography INS winds	35.0	Tromso Bodo Svalbard Reykjavik
4. RDAF C-130	Denmark	Imaging radar (SLAR) Passive microwave imager 35-mm photography	10.0 5.0, 17.0, 34.0	Nord
5. USN-NRL P-3	U.S.	Passive microwave imager Infrared profiler PRT-5 INS winds SSM/I radiometer Environmental sensors Laser profilometer Radar altimeter 35-mm photography	37.0, 90.0, 140.0, 220.0 19.0, 22.0, 31.0, 37.0 10.0, 90.0	Tromso Bodo Reykjavik
6. NASA CV-990	U.S.	Imaging radar (SAR) Passive microwave imager Passive microwave profiler Radar altimeter Short pulse radar Aerial cameras INS winds Air temperature	1.3 19 10, 7, 18.0 13.7 13.7 21.0, 37.0	Reykjavik
7. NASA P-3	U.S.	Laser profilometer Radar altimeter Surface contour radar (SCR)	36.0	Tromso Thule Reykjavik
8. NAF P-3	Norway	AXBT		Andoya
9. ARA Baron	U.S.	Atmospheric boundary layer parameters Survey photography		Svalbard Tromso
10. USN P-3	U.S.	Acoustic gear		Tromso Bodo Reykjavik
11. Helicopters		Microwave scanners Scatterometer Photography	10.0, 18.0, 37.0 1-18.0	Icebreakers

available) remote sensing observations. This requires an extensive surface-based microwave program to relate scattering and emission characteristics to frequency, ice type, and ice surface and physical properties (roughness, dielectric characteristics, temperature, salinity, crystal size).

b. To determine whether certain ice parameters such as ice concentration, ice type and ice roughness can be reliably extracted from the outputs of a combination of active and passive microwave sensors, especially for the MIZ in summer.

c. To develop new applications of remote sensors in this zone, such as the detection of gravity waves as they propagate into the ice and the evolution of melt ponds.

d. To develop models that adequately explain and predict remotely sensed electromagnetic radiation signatures of both ice and ocean features.

A4.3. Airborne remote sensing

A list of possible remote sensing aircraft that could participate in both MIZEX 83 and 84 is given in Table A1. Also listed are potential instrument ensembles for each aircraft and possible bases of operation.

Two types of flights will be made: high-altitude with imaging radars and scanning passive microwave sensors to acquire the mesoscale sequential synoptic images of the entire MIZEX test area;

low-altitude with active and passive microwave instruments to acquire transect data at selected locations within the test area. Thus, two types of remote sensing products will be generated: composite mosaic maps of the entire test area, as shown in Figure 4, and transect images and profiles. In addition, imagery will be made available to the shipborne scientists, either immediately by direct downlink from aircraft to ship, or by transmission to Tromso Telemetry Station and retransmission to the ships.

The aircraft and sensors given in Table A1 can potentially survey such characteristics of the MIZ as the ice edge boundary, ice types and concentration, ice deformation, gravity waves and swell both in the water and in the ice, location of internal wave fields, location of eddies and current boundaries, surface currents, and sea surface winds. Table A2 summarizes the present states of algorithms that utilize the proposed microwave sensor data to extract ice and ocean parameters such as those mentioned above. This table shows which sensor has a demonstrated or potential capability to observe each phenomenon.

An aircraft remote sensing program on a smaller scale and shorter duration than that called for in MIZEX but which used some of the aircraft and sensors given in Table A1 was carried out in the NORSEX experiment. This program serves as a good base for planning the remote sensing programs of the MIZEX pilot and main experiments.

One of the tasks in MIZEX will be to acquire a

Table A2. Sea ice and ocean parameters and sensors.

1—Demonstrated capability 2—Potential capability 3—Ancillary capability

	<i>Imaging radar</i>	<i>Radar altimeter</i>	<i>Passive microwave</i>	<i>Scatterometer</i>	<i>Infrared photography</i>	<i>Infrared imager</i>	<i>Laser profilometer</i>	<i>Infrared profiler</i>	<i>AXBT</i>
Delineation of ice boundary	1	3	.	2	2	1	—	—	—
Location and shape-size of ocean-ice eddies	1	—	2	2	3	2	—	—	—
Floe size distribution	2	—	3	—	1	—	—	—	—
Ice type	2	—	1	1	3	—	—	—	—
Ice roughness	2	3	—	2	—	—	1	—	—
Ocean wave spectra	1	1	—	2	—	—	2	—	—
Ocean waves in ice	1	3	—	—	—	—	3	—	—
Surface wind over water	3	1	2	1	—	—	—	—	—
Sea surface temp	—	—	1	—	—	1	—	1	2
Ocean temp profiles	—	—	—	—	—	—	—	—	1
Ice temp (surface)	—	—	2	—	—	1	—	1	—
Ice concentration	2	2	1	—	3	—	—	—	—

sequential series of high-resolution, synoptic, mesoscale images as frequently as resources and logistics permit. Considering the known space and time scales of key MIZ ice-ocean phenomena, such mesoscale images must be acquired every 2 to 3 days.

Of the observable ice-ocean phenomena listed in Table A2, two require some elaboration: ocean eddy location and tracking, and ocean wave spectra.

Ocean eddies can often be seen in aircraft SAR and SLAR imagery due to the effect of local changes in the atmospheric stability caused by air-sea temperature differences changing from positive (hence stable) to negative (hence unstable). Such sudden spatial changes in atmospheric stability are often accompanied by variations in the local small-scale roughness which is seen in radar images as an abrupt change in radar backscatter. IR images and profiles are also useful in detecting eddies and will be used, when available, to locate and track eddies and frontal boundaries. Past work in temperate latitudes indicates that the mesoscale mapping by SAR and SLAR will be the prime tool for acquiring eddy and ocean front information.

Since wave penetration of the ice is a prime de-

terminant of the structure of the MIZ, wave spectra observations of the ocean adjacent to and within the mesoscale MIZEX area are essential. Aircraft equipped with imaging radars, laser profilometers, and cameras will be used to observe one- and two-dimensional ocean wave spectra. Flight tracks will be flown perpendicular to the wave fronts from a distance of 25 km off the ice edge to a distance of 100 km into the ice. The aircraft tracks will be coordinated with surface measurements with wave buoys. SAR-SLAR imagery will be obtained with flights parallel to the wave fronts at various altitudes. For example, multi-level radar images over the ocean and ice will provide radar backscatter at different incident angles which can be used to improve our understanding of the transfer functions required to extract a two-dimensional wave spectrum.

A4.4. Surface remote sensing

Multispectral measurements of brightness temperature, radar backscatter cross sections, and dielectric property measurements will be made for water and various types of ice during different weather conditions. Table A3 lists the instrument systems.

Two teams will take part in the observational

Table A3. Helicopter- or surface-based remote sensing instruments.

Surface platform	Nation	Instruments	Frequency (GHz)
Drifting-ice ship station	U.S. Univ. of Kansas	Microwave step Scatterometer	1 to 18 selected
		Resonant cavity (Dielectric constant measurements)	1 to 4
	U.S. Univ. of Wash.	Passive microwave Radiometer	10, 18, 37, 90
		Resonant cavity (Dielectric constant measurements)	13.7
	Great Britain SPRI	Passive microwave radiometer	4, 9, 10.4, 21, 36, 94.6
		Microwave scatterometer	10.4
Ice-strengthened ship	Switzerland Univ. of Bern	Infrared radiometer	8 to 14 microns
		Resonant cavity (Dielectric constant measurements)	1
	France CNES	Rainbow microwave active radiometer (ship mounted-step scatterometer)	3-6 GHz (wide swath) 8-18 GHz selected (9, 13.5)
		Resonant cavity	1.3 (5 and 10 possible)
Germany Max Planck	CODAR		HF

program. One measurement group will be located on the ice drifting ship. Its task will be to concentrate on detailed temporal studies of selected ice types. A second group will be placed on an ice edge ship or icebreaker. Its task will be to study different ice types as the ship makes transects into the ice. Helicopter-borne instruments will link both programs and provide high mobility to study ice conditions within the experimental region.

In situ measurements will be made of physical-electrical properties of various ice and snow types present at the active-passive measurement test sites to help in understanding the microwave interaction processes involved. Physical property information to be acquired includes small-scale surface roughness, snow wetness, grain size, salinity distribution, temperature, snow thickness, ice thickness, and scatterers in the ice. Dielectric measurements will be made to describe various ice types at X-L-C bands and 13.7 GHz. Scenes of special interest include thawing and refrozen surfaces; multi-year, first-year and thin ice of various thicknesses; and melt ponds and open water under calm and windy conditions. The measurements will be made in collaboration with ice physicists so that backscatter, brightness temperatures, and physical-electrical properties may be correlated for a given test site (see Section A1.2.3).

To obtain the greatest quantity of coherent information from the summer melt season, we will begin the measurement program at the start of the metamorphic process.

Acquisition of surface remote sensing data is essential at the time of remote sensing overflights.

A summary of the anticipated ground measurements needed to support a remote sensing program is as follows:

<i>Snow</i>	Small-scale microwave roughness at air/snow interface Depth Density Free water content Dielectric constant (if possible)
<i>Ice</i>	Small-scale microwave roughness at air/ice or snow/ice interface Type Depth Density Salinity Free water content Characterization of crystal structure
<i>Ridges</i>	Height Width Block sizes

A4.5. Satellite remote sensing

The satellites and sensors likely to be in operation during MIZEX are given in Table A4. This table also lists possible receiving stations which could provide real-time data recording. Most of the sensors are in the visible and infrared ranges

Table A4. Satellite sensors.

Satellite	Sensor name	Type	Ground station
NOAA	AVHRR	Vis + IR	Tromso (Norway)
METEOR (Soviet)		Vis + IR	Tromso (Norway) Lyngby (Denmark)
DMSP	SSMI	Vis + IR + Microw. (1984)	NORDA (U.S.)
LANDSAT-D	MSS + TM(?)	Vis + IR	Kiruna (Sweden)
MOS (Japan)	MSS	Vis + IR	
NIMBUS-7	CZCS THIR SMMR	Vis IR Microw.	Lannion (France) Lannion (France) Lannion (France)

NOAA = National Oceanic and Atmospheric Administration

DMSP = Defense Meteorological Satellite Program

MOS = Man-time Observation Satellite

AVHRR = Advanced Very High Resolution Radiometer

MSS = Multispectral Scanner

TM = Thematic Mapper

CZCS = Coastal Zone Color Scanner

THIR = Thermal High-resolution Infra-red

SMMR = Scanning Multichannel Microwave Radiometer

SSMI = Special Scanning Microwave Instrument

NORDA = Navy Oceans Research and Development Activity

and are therefore cloud-inhibited. During MIZEX the cloud cover will be persistent, with overcast conditions perhaps 75% of the time, but techniques have been developed to combine cloud-free area images to generate composite maps with infrared data. Meteorological studies will benefit from imagery of the cloud cover itself.

The satellites which can provide important passive microwave data for sea ice parameters during MIZEX are Nimbus 7 and DMSP. Nimbus 7 has already exceeded its design lifetime, but may well still be in operation during 1983 and 1984. DMSP is due for launch in 1984 and will be equipped with a satellite scanning microwave instrument (SSMI).

For operation purposes it is important that an APT receiving facility be available on the ice-strengthened ship.

A4.6. Data transmission and storage

A4.6.1. Transmission in real time

During MIZEX the ice edge ship is largely dedicated to the oceanographic mapping of eddies, bands and other mesoscale features. To accomplish these tasks it must be able to receive real-time remote sensing data on the ice edge disposition, since such features cannot be detected or resolved reliably by the ship itself (on radar) or by its helicopter. A way to achieve this end is to downlink radar data in real-time from a dedicated reconnaissance aircraft. A digital UHF downlink with a line-of-sight range of 100 n.mi. or greater will be available to transmit real-time high-quality imagery to the ship. This downlink system has been developed by Intera in conjunction with two X-band HH digital imaging radars, a SLAR and a SAR. The SLAR operates at 800 m altitude with a swath width of 40 km on both sides; it has a range resolution of 40 m and an azimuth resolution of 9.8 m per 1-km range. The SAR has an along-track resolution of 8 m with multiple looks (4-7) and a range resolution of 6 m or 12 m, with swath widths of 24 or 48 km respectively. Both radars operate in light, highly efficient aircraft (e.g. King Air)

which can be used to cover the entire experiment area using existing airports. The SLAR could be available throughout the experiment while the SAR could be available for a limited number of mapping missions.

While the ice-edge ship is the primary recipient of the downlink, the drifting ice station would also benefit from a knowledge of ice edge conditions and of features within the pack such as large polynyas in the vicinity of the transponder arrays. To achieve this, a cheap, slow-scan TV system with a zoom lens on the transmitting camera could be used to transmit images over voice radio links from the ice edge ship to other ships. Further, since data are recorded on CCTs, it will be possible to provide multiple copies of images to users from various disciplines aboard the ship (e.g. to carry aboard the helicopter); also density sliced images for special purposes (e.g. pressure ridge highlighting for use by the ice properties team).

Additional real-time or near real-time data, which it is hoped will be supplied to the ships within 24 hours, include:

- 1) passive microwave (quick-look images of the mesoscale area showing the configuration of the ice edge and possible eddies)
- 2) infrared images and profiles (as desired)
- 3) radio-transmitting descriptions of sea state and INS winds.

Where direct downlink is unfeasible the information will be relayed via the Tromso Telemetry Station.

A4.6.2. Data storage

An institution will be chosen where all remote sensing data can be stored, processed, analyzed and distributed. Much analysis, of course, will occur at the parent institutions of the participating remote sensing scientists, but there must also be a central location where all MIZEX investigators will have access to the remote sensing data, since almost every program will need to use the data in some way.

APPENDIX B: ACOUSTICS AND MIZEX

Portions of the acoustics research program relate directly to goals of MIZEX, and are described here. The overall acoustics research effort is described in a separate document (Dyer 1982).

The advent of powerful array and other signal processing technology via the microprocessor has revolutionized acoustics research. Of particular value to MIZ research is the potential of tomographic sensing of the mesoscale eddy field and the potential of wide-area mapping of ice-cover roughness. Both are synoptic in character, and can be repeated either continuously or on a schedule governed by the temporal scale of each process.

Acoustic tomography was first suggested by Munk and Wunsch (1978), and the first pilot experiment was carried forward by them and their collaborators in 1981. Preliminary results (Spindel 1980) have high promises of mesoscale eddy delineation in the open ocean. In the MIZ, eddy scales are expected to be considerably less than those at lower latitudes and acoustic paths are expected to be of considerably different character than those encountered in the first tomography experiment. For these reasons acoustic research in the MIZ will focus upon path identification, signal stability and coherence, and signal degradation associated with ice-related noise and rough surface scattering. Such knowledge is essential to reasoned deployment of a MIZ tomographic system (Spiesberger et al. 1980, Spindel 1980), and will begin to be acquired in the 1983 experiment. A preliminary tomographic experiment may well be sensible for MIZEX 1984, but more likely further work will be required on path identification and stability, and on environmental parameters affecting system design. We can reasonably expect deployment of a tomographic system for the follow-on MIZEX winter experiment, and useful but partial data on eddy structure for the 1984 summer experiment.

Wide-area mapping of ice roughness was first proposed by Dyer (1981), based on acoustic back-

scatter results of 1978 and 1980 Arctic experiments. Such data delineate areas of ice cover in excess of 10^5 km^2 , and a similar technique could readily cover the planned MIZ cell ($4 \times 10^4 \text{ km}^2$). The 1983 experiment would be used to test a new drifting sensor technology required for array processing, to compare preliminary roughness synopses with direct measurements of ice roughness in a few localities, and to optimize system configuration based on environmental effects such as ice-related noise and rough bottom scattering. We do not know how well such a system can discriminate rough open water from rough ice, and ultimately doppler processing may have to be used to do so. We do believe, however, that smooth open water, such as in large leads and polynyas, can be discriminated. These questions could be addressed in the 1983 experiment, but more likely would be in 1984 MIZEX, when a larger array with more useful resolving power would be deployed. We can reasonably expect MIZEX 1984 to result in ice roughness synopses in coordination with aircraft-acquired imagery and direct ice measurements.

Ice roughness backscatter might yield estimates of rms roughness depth, correlation radius and/or number of roughness elements per unit area, depending upon the model applied to the data. Thus the MIZEX 1984 includes an appropriate ice backscatter modeling effort which, in collaboration with other MIZEX researches, would lead to a validated model.

Recent research also points to the potential of ice-cover forward scatter as a different way to extract roughness (Medwin et al. 1979). In certain regimes the forward scatter Biot boundary wave can be measured to extract the roughness-volume unit area. While not a synoptic technique, forward-scatter experiments along a single line would serve as a valuable check or adjunct to the backscatter results. Such forward scatter experiments are planned for MIZEX 1984.

APPENDIX C: BIOLOGICAL PROGRAM

The Marginal Ice Zone Experiment (MIZEX) is a mesoscale experiment designed to elucidate the physical processes in which air, ocean and ice interact in the vicinity of the ice edge. These interactions also produce a unique set of conditions which support an unusual biological system at the ice edge. This unique system is characterized by elevated standing stocks of nearly all trophic levels, i.e. phytoplankton, zooplankton, fish, birds and mammals (Alexander 1980). Only by understanding the dynamics of the physical processes occurring at the ice edge can we explain the increased biological activity in this area.

The initial MIZ summer experiment will be conducted over the course of two years. Biological participation in 1983 will consist of an investigation of the distribution of nutrients (nitrate, nitrite, ammonium, phosphate, silicate), phytoplankton and suspended particulates (chlorophyll *a*, phytoplankton species, particulate carbon), and zooplankton species composition in a region near the ice edge. Although no data exist on the spatial extent of the elevated biological activity, we expect that the investigation will be mesoscale (10–100 km) in nature and be limited to the upper 100 m of the water column. Efforts will be made to collect biological samples so that the data will corroborate the physical oceanographic measurements being made by other MIZEX components, e.g. eddy properties and transport, ice edge upwelling, ocean fronts, and small-scale processes.

In 1984 a larger, more complete set of biological measurements is planned. A description of the main biological program has been prepared by M.J. Dunbar with input from several colleagues from Canada, the United States, Norway and Denmark (Dunbar 1982). Some of the main areas to be investigated in more detail are extracted from this document and summarized below.

1) *Water chemistry.* Concentrations of nutrients (as in 1983), oxygen, carbon dioxide-bicarbonate, and trace metals, particularly those which might impact phytoplankton growth, will be studied. Partitioning of chemical constituents in the ice-brine-ocean components is of particular interest. Studies of long-distance transport of radioactive contaminants and other environmental contaminants are also planned. The chemical composition and flux of particulate matter from the euphotic zone will be determined to assess its role in deep-sea metabolism.

2) *Microbiology.* The role of bacteria in nutrient regeneration and energy transfer of the Arctic Ocean and in the flocculation of particulate matter will be assessed.

3) *Primary production.* Studies will be made to determine the causes for the extent of the observed phytoplankton bloom in the MIZ and to determine the physiological status of the phytoplankton under dense ice, at the ice edge and in the open ocean. Special attention will be given to ice algae: their concentration, their role in "seeding" the bloom, their growth rates, and their sinking rates. In conjunction with nutrient analyses, rates of nitrate, ammonium and silicate uptake will be measured by the use of isotopes; carbon uptake and the response of the plankton to light will be measured. Phytoplankton species composition will be monitored.

4) *Zooplankton.* An analysis of the vertical distribution patterns of the dominant zooplankton in the MIZ will be conducted in conjunction with grazing studies which will determine the impact of biological removal of phytoplankton on the particulate matter distribution. A detailed description of zooplankton species composition and life stages will also be provided.

5) *Higher trophic levels—birds, mammals, fishes.* Birds will be identified from on board ship and their distributions analyzed with respect to food and habitat. Gut contents of species will be analyzed if possible. The behavior and abundance of marine mammals will be analyzed with respect to their association with the ice edge. Analysis of fisheries stocks may be impossible during MIZEX although acoustic methods potentially could be used to assess the biomass of various species.

The planned biological components of MIZEX in both 1983 and 1984 are of great interest in themselves, given the dearth of knowledge concerning energy flow, species composition and distribution, and potential yield from this important ecosystem. Yet the biological data also can support and corroborate physical measurements, particularly because of the time lags often inherent in biological processes; conversely, without information on the physical processes in the MIZ interpretation of the biological data would be greatly hindered. When used in conjunction, biological and physical data provide a powerful tool for understanding the unique processes and interactions occurring at the marginal ice zone.

APPENDIX D: MIZEX ORGANIZATION

This appendix summarizes MIZEX management and describes the responsibilities of the various elements. An organizational chart is shown in Figure 7.

MIZEX Science Group

The MIXEX Science Group constitutes the corporate scientific and policy directorate for the MIZEX project. It is composed of Science Discipline Chairmen, National Coordinators, and, *ex officio*,* the Executive Officer and the Logistics Manager. The MIZEX Executive Officer will also serve as Secretary of the Science Group, maintaining records and reporting the minutes of Science Group meetings.

The overall functions and responsibilities of the MIZEX Science Group are:

Establishing the program objectives

Assuring science quality and scientific control

Planning, including overview of the development and preparation of the experimental and operational plans

Providing policy guidelines

Providing general program coordination

Evaluating, as requested and as appropriate, MIZEX science research proposals

Providing liaison with the International Science Advisory Board or group

Carrying out other agreed-upon functions.

In addition, the National Coordinators are responsible for:

Providing own nation coordination and communication

Providing liaison with own nation's science advisory group and funding agencies

Effecting international coordination jointly with other national coordinators.

Similarly, the Science Discipline Chairmen are additionally responsible for:

Organizing science interests to reflect and represent their discipline in the MIZEX program

Providing input from their discipline into the MIZEX experimental and operational plans and assisting in the development and preparation of these plans.

MIZEX Executive Committee

The MIXEX Science Group will elect a Chairman and Vice Chairman for a term of two years. The MIZEX Executive Committee will consist of the Science Group Chairman, who will also serve as Chairman of the Executive Committee, the Vice Chairman, and one to two additional members elected by the Science Group for a term of two years. Incumbents can be re-elected for additional or consecutive terms of office. The MIZEX Executive Officer and the Logistics Manager will also serve as *ex officio* members of the Executive Committee.

The Executive Committee will act for the Science Group on all regular management and operational matters, in accordance with the stated objectives and established policies of the MIZEX project. The Chairman will report to the Science Group on activities of the Executive Committee by the most effective means, including memoranda, newsletters, electronic mail, and oral summaries at Science Group meetings.

**ex officio* are non-voting members.

MIZEX Chairman

The Chairman will be responsible for:

- Assuring overall coordination of the MIZEX project
- Maintaining the scientific coherence of the project
- Assuring the timely development, preparation and promulgation of experimental and operational plans
- Establishing practicable, safe procedures for field operations
- Assuring the appointment and designation of key personnel for the management of field operations
- Coordinating and reporting on the actions of the MIZEX Executive Committee.

MIZEX Vice Chairman

The Vice Chairman will assist the Chairman in the execution of his duties and will act for the Chairman in his absence.

MIZEX Executive Officer

The MIZEX Executive Officer is the senior MIZEX staff member responsible to the MIZEX Science Group, the MIZEX Chairman and the principal funding agencies for:

- Coordinating and executing the plans and policies developed with and approved by the MIZEX Science Group
- Developing operational plans in conjunction with the MIZEX Field Coordinator, the Principal Investigators, and the Logistics Manager
- Assuring the necessary clearances for aircraft, ships and personnel have been obtained
- Assuring that all necessary logistics preparations are completed in a timely manner
- Arranging for and convening planning meetings and workshops as necessary to progress the work of the MIZEX Science Group and Executive Committee
- Serving as Secretary to the MIZEX Science Group and Executive Committee
- Establishing the MIZEX data management plan and assuring the exchange of data among scientific groups
- Assuring the preparation and publication of preliminary data summaries and research reports through the MIZEX Bulletin
- Preparing and assembling MIZEX summary reports, information and notices in a timely and expeditious manner through newsletters, memoranda, electronic mail and regular correspondence
- Arranging for the conduct of and/or participation in national and international symposia and conferences where results of the MIZEX project can be presented, and for the submission of papers to regular and special issues of appropriate journals
- Carrying out such other responsibilities as may be appropriately assigned.

MIZEX Logistics Manager

The Logistics Manager will assist the Executive Officer in the execution of his assigned duties. The Logistics Manager will act for the Executive Officer on assigned tasks and when so directed by the Executive Officer or the MIZEX Science Group Chairman. The Logistics Manager will be directly responsible for:

- Establishing, in consultation with the MIZEX Chairman, the MIZEX Field Coordinator and the Principal Investigators, the logistics requirements for all MIZEX operations
- Assuring the overall adequacy of logistics support for the field operations
- Coordinating and arranging for the needed support within the available resources
- Assuring and overseeing the safety of scientific activities in the field

Establishing and coordinating the schedule for cargo shipment and personnel management in the pre- and post-field operational phases
Providing liaison at Tromso, Longyearbyen and other locations as required
Providing support and coordination for field station aircraft operations, including ship-based helicopter support
Carrying out such other responsibilities as may be appropriately assigned.

MIZEX Bulletin

The MIZEX Bulletin is established as a communication device to rapidly disseminate MIZEX results in the form of preliminary data summaries, initial research reports, and pre-prints of journal articles. The Bulletin is one element of the permanent record and data management of the MIZEX program. The Bulletin will not be a reviewed journal, therefore inclusion of articles in it will not preclude later submission to regular journals.

The staff of the Bulletin will consist of two science editors elected by the Science Committee together with a technical editor. The science editors will be responsible for:

Receiving and briefly examining data summaries and manuscripts
Overseeing the scientific content and general quality of the Bulletin.
Organizing special theme issues of the Bulletin

The technical editor will be responsible for:

Editing manuscripts and overseeing production of the Bulletin
Maintaining the MIZEX general mailing list for Bulletin distribution
Assuring the timely publication and distribution of each Bulletin issue.
For at least the next two years this Bulletin will be produced at CRREL as a series of Special Reports.

MIZEX Field Coordinator

The MIZEX Field Coordinator will be the Senior Scientist for each MIZEX field operation. The individual will be designated by the MIZEX Science Group Chairman after consultation with the MIZEX Science Group and the cognizant managers of the principal funding agencies supporting each operation. The specific duties, responsibilities and authority of the MIZEX Field Coordinator and all subordinate field operation positions will be set forth in a section of, and as part of, each MIZEX Operational Plan.

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